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THE TRANSPORTATION OF GASES, LIQUIDS AND SOLIDS

OSKAR NAGEL

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THE TRANSPORTATION

OF

GASES, LIQUIDS AND SOLIDS

BY MEANS OF

STEAM, COMPRESSED AIR AND PRESSURE WATER

A COMPLETE DESCRIPTION OF THE THEORY, CONSTRUCTION, OPERATION AND APPLICATION OF JET MACHINES, MONTEJUS, SPRAY NOZZLES, ETC., FOR CHEMICAL, METALLURGICAL, MINING, MECHANICAL AND CIVIL ENGINEERS

BY

OSKAR NAGEL, PH.D.

CONSULTING CHEMICAL ENGINEER, AUTHOR OF "THE MECHANICAL APPLIANCES," MEMBER SOC. CHEM. IND.

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PREFACE.

Though the application of steam, compressed air and pressure water for transportation purposes has been steadily increasing for the last twenty-five years, there is, as yet, no book on the market covering the description of these machines.

Since the present book is the first on this important subject, I hope that it will be welcome to chemical, metallurgical, mining, mechanical and also civil engineers. Up to this time the information regarding these appliances was widely scattered in engineering journals, various books on applied mechanics, text-books on thermodynamics and in manufacturers' catalogues.

I have described in every chapter the construction, theory, operation and application of each apparatus, and have also inserted the necessary tables of dimensions and capacities. The first part of the book deals with the transportation of gases, the second with the transportation of liquids, the third with the transportation of solids. In the fourth part the appliances for atomizing liquids are described, while the fifth contains a discussion of jet condensers. The intimate relation of the fourth and fifth parts will be readily understood from the respective descriptions. The sixth part deals with the theory of the jet machines.

Although the book is intended for the industrial engineer, it is of equal value as a text-book, since it gives also the fundamental principles, besides the latest experimental data and applications.

OSKAR NAGEL, PH.D.

NEW YORK, October, 1909.

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FIRST PART.

TRANSPORTATION OF GASES.

Steam-Jet Apparatus for Moving Air and Gases.

The application of the steam jet for moving air and gases shows very great economy and efficiency if the instruments are properly constructed and well proportioned. The variety of application and the corresponding difference in the proportion of the instruments is practically without limit, depending on the variation of volume and counter-pressure or the degree of rarefaction to be overcome. The limit of rarefaction is 25 inches of mercury, and the limit of counter-pressure one seventh of the steam pressure of the actuating jet.

By regulating the area of the actuating jet and the steam pressure, the capacity and general effect of the same instrument can be varied within certain limits, so that instruments of certain sizes and dimensions can, by proper adjustment, be made correct and effective for varying conditions.

These air and gas blowers and exhausters are divided into two classes:

1. Machines for the purpose of overcoming a certain low counter-pressure or rarefaction of, say, from one half inch to 6 inches of water. These machines attain the desideratum of extreme volumes and are called blowers and ventilators.

2. Machines for the purpose of overcoming a high counter-pressure up to one seventh the steam pressure, or exhausting against a high rarefaction of from 10 to 25 inches of mercury. These machines attain the desideratum of extreme pressures and are called compressors and exhausters.

Steam-Jet Blower and Water-Spray Blower.

Fig. 1 shows a jet blower with regulating spindle, Fig. 2 a blower without spindle. The steam enters at the steam connection *S* and, by passing at high velocity through the nozzles *M*, draws the air in at *A*, the steam-air mixture being discharged at *D*. *R* is the regu-

lating spindle, which allows the regulation of the quantity of steam admitted to the blower. Starting and stopping is effected by fully opening or closing a valve in the steam line.

FIG. 1. BLOWER WITH SPINDLE.

FIG. 2. BLOWER WITHOUT SPINDLE.

Table I.[1] gives the dimensions of these blowers, Table II. the capacities at 60 pounds steam pressure, when discharging against a counter-pressure of from one half to 2 inches of water.

By an increase of steam pressure and higher position of the

[1] The capacities and dimensions of the instruments refer to machines built by the Schutte and Koerting Co., of Philadelphia.

spindle, both volume and counter-pressure are increased; by the reversed operation a corresponding decrease is effected.

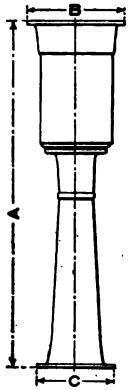


FIG. 3. BLOWER.

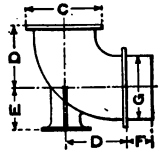


FIG. 4. ELBOW.

TABLE I. (See Figs. 3 and 4.)

Size. Diameter of Discharge.	Blower. Inches.			Elbow. Inches.			
	A.	*B.*	*C.*	*D.*	*E.*	*F.*	*G.*
3	19¼	7	5½	4¾	3	9	3½
4	26¼	8	6½	5⅝	3½	9	4½
5	34⅜	11	8½	6¼	4	9	5½
6	41⅜	12	9½	7	4½	12	6½
7	46¾	14	11	7½	5	12	7½
8	57¾	15	12	8	6	16	8½
10	65⅜	17½	13	10	7	16	10½
12	75⅜	19½	15	12	8	16	12¾
14	86¼	21½	17½	14	9	16	14¾
18	111	23	23	18	12	16	18¾
24							
32							

TABLE II.

Size. Diameter of Discharge. Inches.	Capacity in Cubic Feet per Hour.	Diameter in Inches.		Max. Coal Burnt per Hour in Pounds.
		Steam.	Inlet.	
3	10,000	⅜	4	50
4	20,000	½	5	100
5	30,000	½	8	150
6	45,000	¾	9	225
7	60,000	¾	11	300
8	90,000	¾	12	450
10	120,000	1	14	600
12	180,000	1	16	900
14	240,000	1¼	18	1,200
18	500,000	1½	24	2,500
24	1,000,000	2	32	5,000
32	2,000,000	2½	42	10,000

Applications.—The blower, when used for increasing the draft under a boiler, produces a blast perfectly under control and at the least expenditure of steam. Its use is of advantage in almost every fireplace, but is indispensable when inferior grades of fuel, such as screenings, coke breeze and other refuse products are to be burnt.

The greater heat produced by a blast naturally increases the steaming capacity of boilers. Furthermore, when draft is defective, a blower of suitable size will create a more perfect combustion.

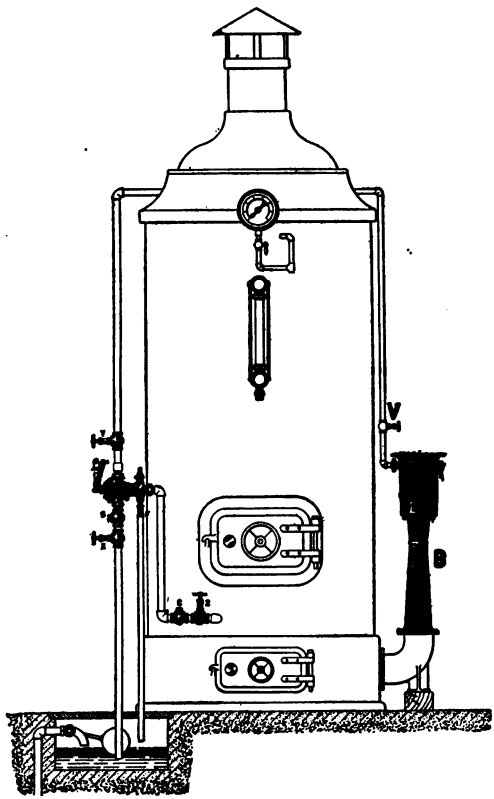


FIG. 5. BLOWER ON UPRIGHT BOILER.

The steam-jet blower also provides a means of increasing the capacity of boilers beyond their rating, which is of great convenience in cases of emergency and also for boilers, which are "overloaded" for short periods only.

Fig. 5 shows a blower installed on a vertical boiler, Fig. 6 an installation on a reverberatory furnace. Fig. 7 illustrates a blower connected to a horizontal boiler.

In order to obviate or reduce the noise caused by the action of the blower, an air conduit, as shown in Fig. 8, should be attached to the top of the instrument. This conduit should lead straight up to the top of the boiler-room, or should be extended through the roof or a side wall to the outside.

Fig. 9 shows a blower on a retort furnace in a gas house. Fig. 10 shows the connection to a gas producer. In this application the proper size of the instrument has to be selected most carefully,

calculating 80 cubic feet of air for the gasification of one pound of coal.

Fig. 11 illustrates a blower connected to a scrubber.

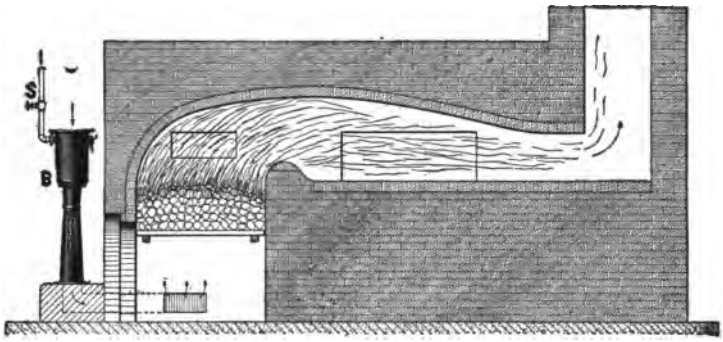


FIG. 6. BLOWER ON FURNACE.

In all cases where this machine is used as a blower, connection is made to the bottom flange. It can be placed vertically or horizontally. However it is generally placed vertically on an elbow attached to the side wall or on a brick flue carried from the ash pit through the side wall. The passage leading into the ash pit

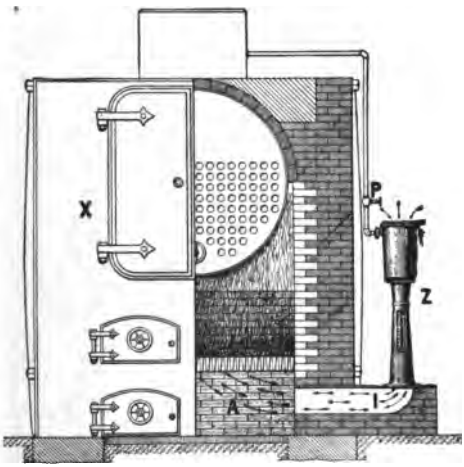


FIG. 7. BLOWER ON HORIZONTAL BOILER.

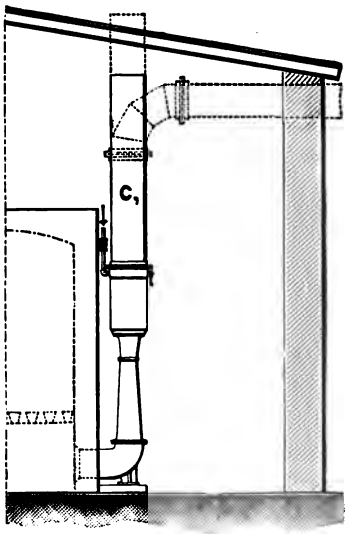


FIG. 8. OBVIATING NOISE.

must be from the front side or back, as the air, if entering from below, would blow a hole through the fire bed and thereby prevent the proper distribution of the blast under the grate.

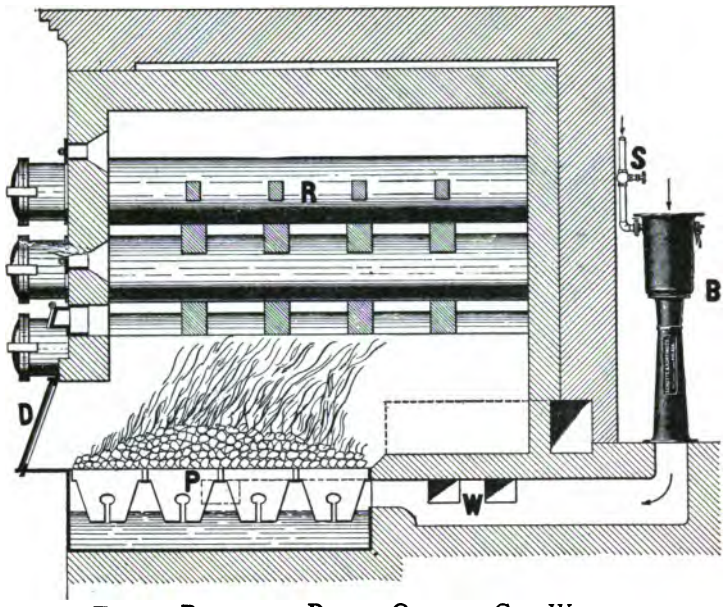


FIG. 9. BLOWER ON RETORT OVEN IN GAS WORKS.

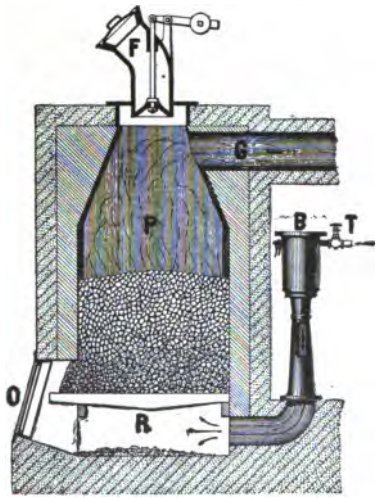


FIG. 10. BLOWER ON GAS PRODUCER.

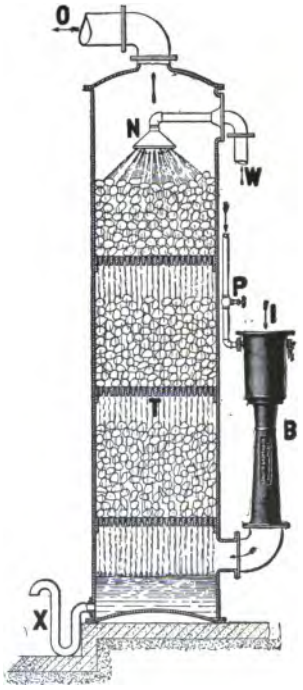


FIG. 11. BLOWER ON SCRUBBER.

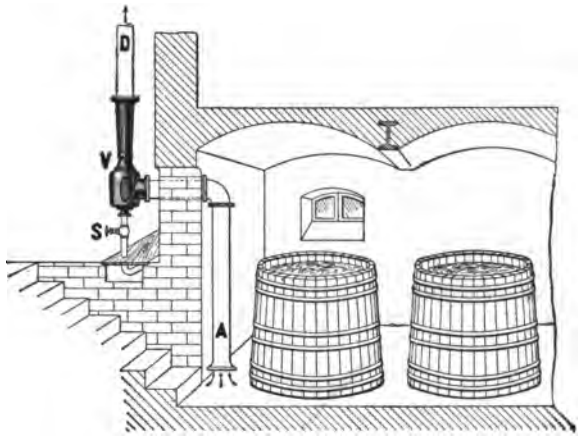


FIG. 12. BLOWER AS VENTILATOR.

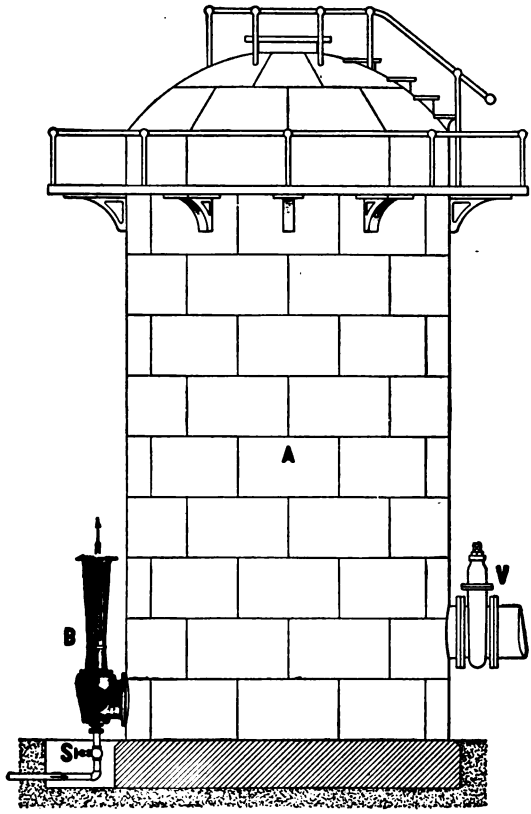


FIG. 13. BLOWER ON COWPER STOVE.

When the jet blower is used for exhausting, *i. e.*, as ventilator, connection is made to the top flange. The working and capacity is not altered thereby. Here also the moving power is a steam jet issuing from a nozzle. The jet traverses other nozzles of larger diameter, draws the air in and carries it along, imparting a certain velocity to same.

The principal applications of the ventilator are:

Removing foul air or gases, Fig. 12.

In mines, workshops and ships, as a substitute for fans.

The simplicity and low price make it applicable for temporary work, where ventilation with other appliances is hardly possible, for instance during the sinking of shafts, deep wells and foundations.

Removing vapors from dryers.

For the evaporation of liquids and the drying of various substances, by drawing hot chimney gases through or over the liquid or solid substances.

Cooling Cowper stoves, Fig. 13. For many years the cooling of Cowper stoves, when shut down for cleaning or repair, has been dependent on the chimney draft. This process of cooling was naturally very slow, as the draft decreases with the progressing cooling. By the application of ventilators the cooling is considerably accelerated, as by the sucking action a strong current of fresh air is produced. The air is drawn in at the open louvres at the top. Three ventilators are placed at the foot of each stove. The largest apparatus actually made for this purpose has a capacity of about 8,000 cubic feet per minute. The ventilators are of wrought iron and are easily fitted and removed.

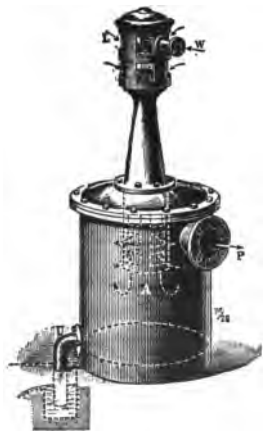


FIG. 14. WATER-SPRAY BLOWER.

Water-spray Undergrate Blower.— This machine serves the same purpose as the steam-jet type of apparatus : it brings air under pressure for firing or other purposes. It can be used in connection with steam boilers, gas producers and heating furnaces, in fact in all places where high counter-pressures are met with and where a

steam-jet blower is usually employed. But, while the air delivered by the steam-jet blower is moist, the air delivered by the water-spray blower is nearly dry, as the water used in the operation is separated again. For coals containing a high percentage of moisture this apparatus is especially suitable. The flow of the water and air is easily understood from Fig. 14. The effective working of this blower depends upon a spray nozzle, which produces a conical jet of fine drops of water, thereby offering a large surface to the induced air. Economy, reliability, noiselessness, convenience and low first cost are the advantages of this apparatus. Table III. shows the capacities.

TABLE III.

Diameter of Discharge in Inches.	Capacity in Cubic Feet per Hour at 90 lbs. Water Pressure.	Diameter of Water Pipe in Inches.
6	8,000	½
8	16,000	¾
10	25,000	1
12	32,000	1¼
14	40,000	1½
18	60,000	1½
24	100,000	2

CHIMNEY VENTILATORS OR BLAST NOZZLES.

Chimney ventilators are used to improve the draft of chimneys, if by the latter the products of combustion are not carried away with the necessary velocity. The working of a chimney might be unsatisfactory on account of its insufficient height or width, or because the cross sections of the flues are too small. Other reasons are too low a temperature in the chimney or atmospheric conditions.

The chimney ventilators belong to the class of jet apparatus. They contain a series of nozzles, in which the motive power of a small steam jet is utilized for moving the gases. Fig. 15 illustrates such an apparatus.

The principal advantages are: Improving of draft, more perfect combustion, increase of evaporating capacity of boilers and capacity of furnaces, absence of moving parts and ability to resist a temperature of 1000° Fahrenheit.

The capacities are given in Table IV.

These ventilators must be placed in the middle of the chimney, just above the entrance of the main flue. All sharp corners at the entrance of the main flue into the chimney must be beveled at

an angle of 45°. When the ventilator replaces a chimney, as for instance in temporary furnaces, it is put over the main flue upon a brick foundation covered with a cast-iron plate. The ventilator is connected to this plate with the flange of its largest nozzle. The steam pipe, which must be of the size indicated in the table, has to be cleaned out with high pressure steam before connection is made.

FIG. 15. BLAST NOZZLE.

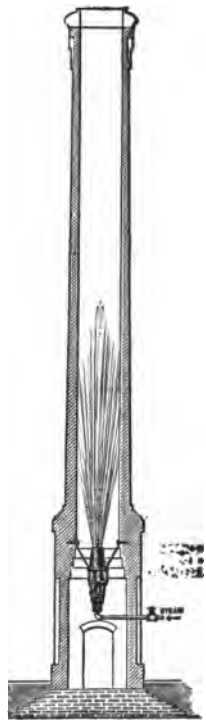


FIG. 16. CHIMNEY VENTILATOR.

Fig. 16 shows a ventilator in a chimney, Fig. 17 a nozzle attached to the stack of a heating or puddling furnace, Fig. 18 a nozzle suspended in a stack and Fig. 19 a nozzle suspended in the ventilating flue of a drying room.

The ventilators are so constructed that they need no steam when the fire is started. If the ventilator gives sufficient draft with the steam valve closed, then keep the valve closed; otherwise open the valve slightly. To stop the action of the ventilator the steam valve is closed.

These ventilators are specially applicable for coke ovens in order

to utilize the waste heat of the coke gases for heating the boilers. With ordinary chimneys this heat is almost entirely lost, because the necessary suction of 2½–3-inch water gauge cannot be obtained.

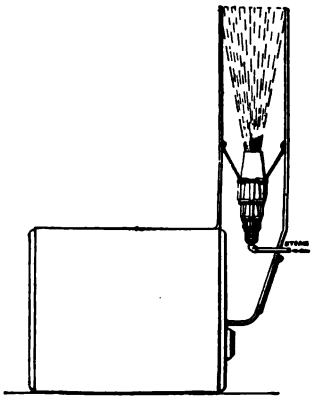


FIG. 17. NOZZLE ATTACHED TO STACK.

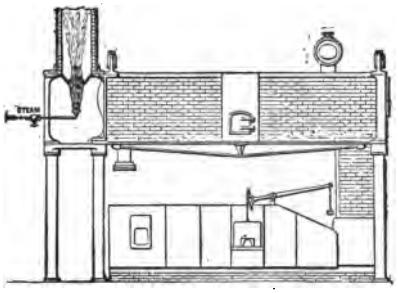


FIG. 18. NOZZLE IN STACK.

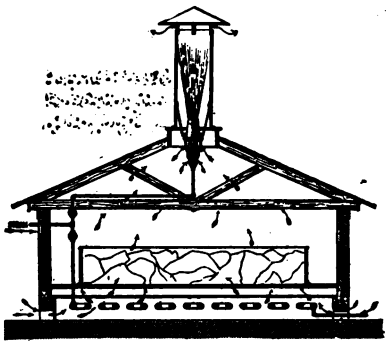


FIG. 19. NOZZLE IN FLUE OF DRYING ROOM.

TABLE IV.

Size No.	Size of Stack.	Diameter of Steam Pipe.
00	Up to 8″	⅜
0	9 " 11	½
1	12 " 15	½
1½	16 " 19	¾
2	20 " 23	¾
2½	24 " 28	¾
3	29 " 33	1
3½	34 " 40	1
4	41 " 50	1¼
6	51 " 72	1½
8	73 " 96	2
10	97 and above	2½

With ventilators this is easily effected. Another advantage offered by ventilators is the greater velocity at which the gases are withdrawn, so that the ovens can be charged at shorter intervals.

For the removal of noxious vapors in chemical works these blast nozzles are made of lead, either with fixed steam nozzle or with

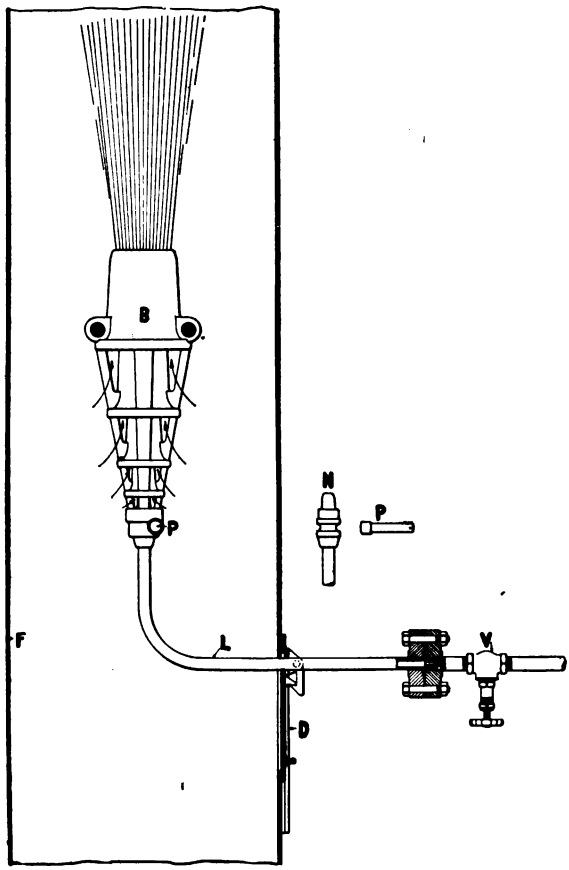


FIG. 20. LEAD BLAST NOZZLE.

removable steam nozzle (Fig. 20). The latter has the advantage that the steam nozzle can be replaced without taking the blast nozzle from the flue.

In Fig. 20, which shows a typical installation in a chemical factory to keep up a uniform draft on burners and in the chambers independent of the atmospheric conditions, *B* is the lead blast nozzle

installed in the flue, *D* the door in the flue to inspect the apparatus and to take the blast nozzle out, *F* the flue, *P* the pin to hold the removable steam nozzle, *N* the steam nozzle, *L* a lead pipe, *V* the steam valve.

Steam-Jet Exhausters and Compressors.

These instruments produce a pressure up to one seventh of the steam pressure (or 12 feet of water) or a vacuum of 22 feet of

Fig. 21. Flanged Exhauster.

Fig. 22. Screwed Exhauster.

water (or 20 inches of mercury), if the pressure of the steam used is 45 pounds. Specially constructed machines of this kind will produce a pressure of 15 feet or a vacuum of 28 feet of water.

Fig. 21 shows a flanged, Fig. 22 a screwed exhauster. *P* is the regulating spindle; the steam enters at *S*, draws the air or gas in at *GE*, the steam-air or steam-gas mixture being discharged through *D*.

The sizes and capacities are given in Table V.

TABLE V.

Size Diam. of Air Pipe in Ins.	Capacity per Hour in Cubic Feet.	Diam. of Steam Pipe.	Size Diam. of Air Pipe in Ins.	Capacity per Hour in Cubic Feet.	Diam. of Steam Pipe.
¼	100	⅛	3	12,000	1¼
½	300	¼	4	18,000	1½
¾	600	⅜	5	27,000	2
1	1,000	⅜	6	35,000	2
1½	2,000	½	7	48,000	2½
2	4,000	¾	8	60,000	3
2½	6,000	1			

As a jet apparatus of this kind has no moving parts, needs practically no repairs, is of low first cost and is simply inserted in the pipe line it is in many cases preferable to an ordinary air-pump.

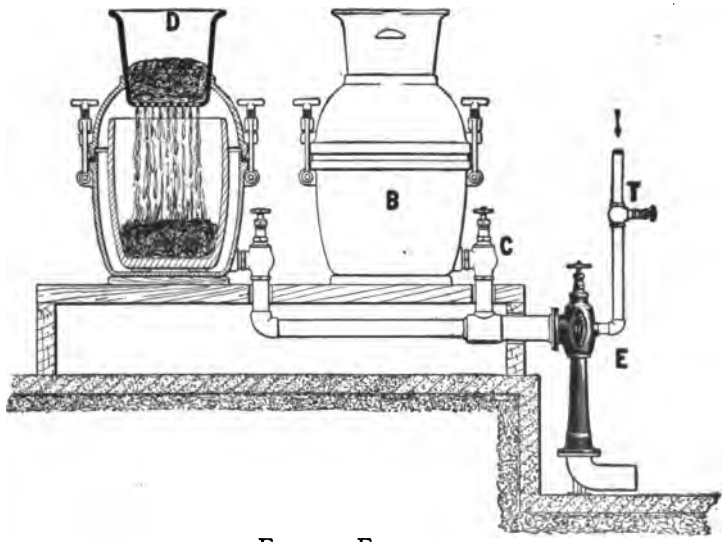


FIG. 23. FILTRATION.

The exhausters and compressors are used for the purpose of drawing gases through liquors, or air through the vacuum box of paper machines, to rarefy creosoting tanks, to prime centrifugal pumps, to lift tar and acids, to oxidize caustic liquors in alkali

works, to facilitate the filtering process by creating a partial vacuum under the filters and as agitators for liquors. The last-mentioned application will be discussed in the next chapter.

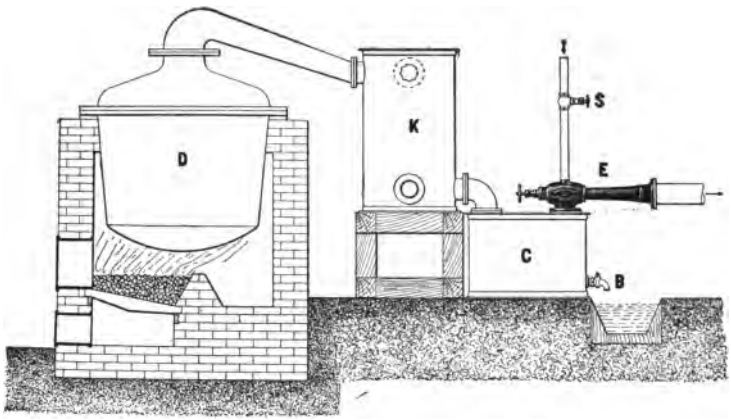


FIG. 24. DISTILLATION.

An installation for facilitating filtration is shown in Fig. 23. *B* is the filter pot, *C* a stop valve, *E* the steam-jet exhauster and *T* the steam pipe. Fig. 24 illustrates an exhauster connected to a distilling plant. *C* is the condenser, *D* the vacuum kettle, *E* the exhauster, *K* the cooler and *S* the steam supply. If the non-condensable gases attack iron or brass, these machines are made of suitable material.

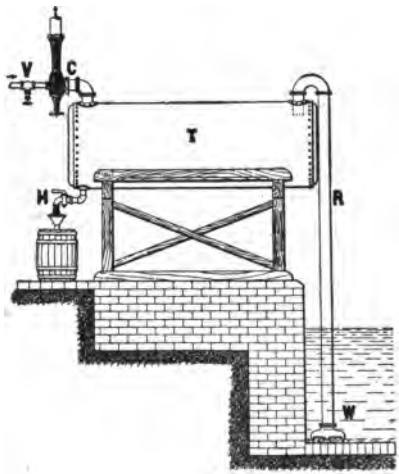


FIG. 25. LIFTING LIQUIDS.

Viscous liquids and liquors which tend to clog up an ordinary pump, and chemicals that attack pumps and cannot be lifted by steam-jet syphons on account of the diluting effect of the steam, are successfully lifted by means of these exhausters. The height of the lift depends on the specific gravity of the material. Liquids of the same specific gravity as water can be lifted 22 feet. Fig. 25 shows such an instal-

lation. *C* is the steam-jet exhauster, *H* the discharge cock, *R* the suction pipe, *T* a tank, *V* the steam pipe.

The same principle can be used with pipe lines connecting water wells, Fig. 26. In such cases an air vessel *A* is useful for collecting the air. Show glasses *G* are arranged on the air vessel in order

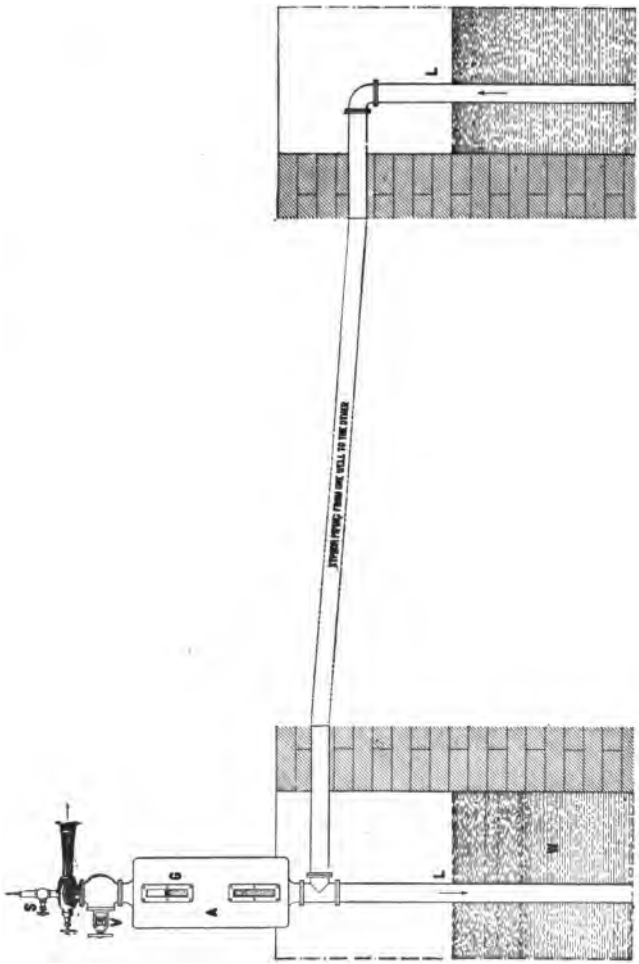


FIG. 26. CONNECTING WELLS.

to ascertain when the exhauster is to be started again. *E* is the exhauster, *L* the syphon pipe, *S* the steam supply and *W* the wells.

Fig. 27 shows an exhauster arranged for pressing air or gases through liquids for the purpose of agitating, saturating or treating a liquid with air or gases. *C* is the material to be treated, *D* the

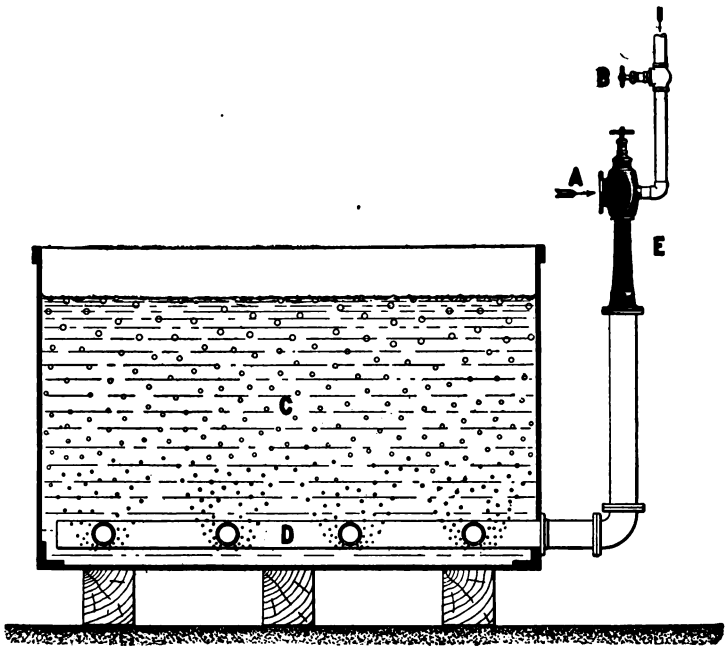


FIG. 27. SUCKING AIR THROUGH LIQUIDS.

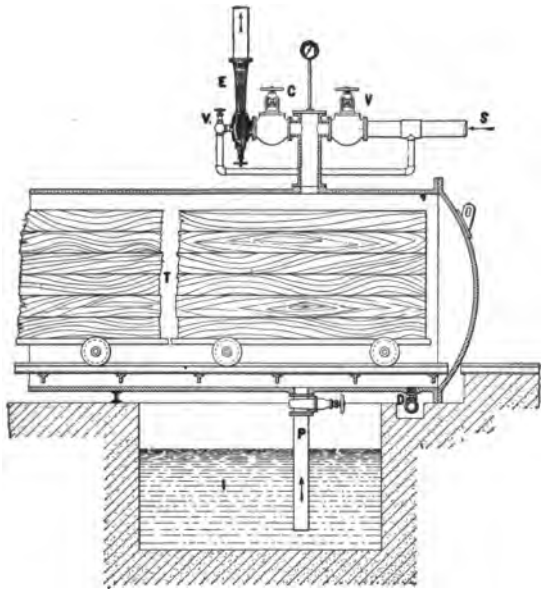


FIG. 28. CREOSOTING TANK.

air discharge pipe and *E* the exhauster. The application to creosoting and impregnating tanks, which is much simpler and cheaper than the use of an air-pump, is illustrated in Fig. 28. *E* is the exhauster, *P* the suction pipe from the chamber containing the solution for impregnating, *S* the steam supply and *T* the impregnating tank.

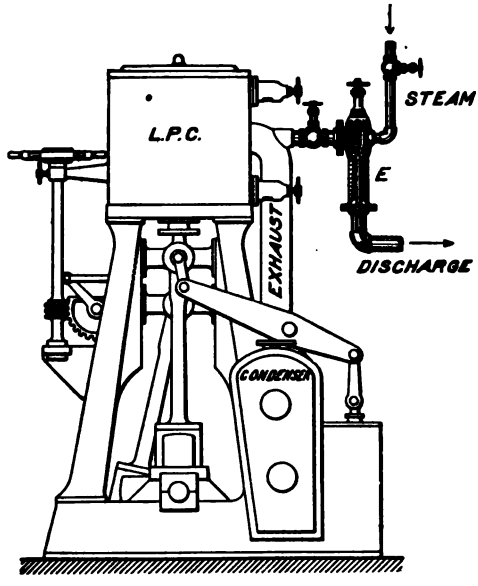


FIG. 29. CONDENSING ENGINE.

The application of this apparatus to a condensing engine is shown in Fig. 29, to a centrifugal pump in Fig. 30.

Regarding the operation of these exhausters, it is to be stated that the proper position of the spindle at the normal pressure of 45 pounds is half way down. With an increase or decrease of the steam pressure, the spindle has to be screwed in or out respectively, in order to get the best efficiency. Regulation should always be effected by means of the spindle, but never by handling a cock or valve in the steam line.

In an apparatus used for forcing air an increase of steam pressure and an enlarged steam opening (effected by drawing out the spindle) will produce an increase of pressure; this, however, is not the case with an apparatus for drawing air. If in such an instrument the spindle is drawn out beyond a certain point the drawing power of the exhauster is decreased and the consumption of steam increased.

Finally we want to mention the steam-jet laboratory exhauster, Fig. 30A, which produces a high vacuum (up to 24 inches in mercury) and is successfully used for removing or rarefying air, for filtering and other operations, where no condensable vapors have to be handled. With a steam pressure of 50 pounds a vacuum of 24 inches of mercury will be produced by this instrument in a one-gallon vessel in 7 seconds.

Steam-Jet Agitators.

Many industries require a means of mixing and dissolving chemicals in water or other liquids. As in many cases mechanical stirrers do not give the desired effect, steam-jet agitators are widely used. They are of the same construction as the agitators shown in Fig. 21 and their action is based upon the same principle, *i. e.*, a steam-jet issuing from a small nozzle into a larger one carries along the surrounding air at a velocity sufficient to overcome a pressure of fully eight feet of water. The air escapes with great force through the perforations of the pipe provided at the bottom of the tank and causes a violent and thorough agitation of the liquid and the solid materials contained in same. These agitators are extremely simple in construction, are easily connected and conveniently handled. They have no moving parts, cost little, do not require any attention and are very economical as regards the consumption of steam.

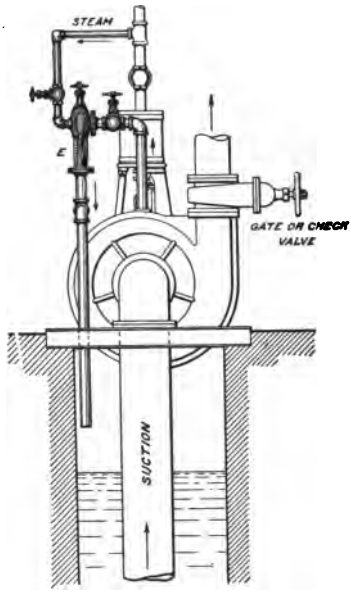


Fig. 30. Centrifugal Pump.

Fig. 31 shows the installation of an agitator in a tannery pit, Fig. 32 the application in a chemical factory. The agitator has to be connected in such a manner that its head stands above the highest level of the liquid. The air-distributing pipes have two rows of perforations, equally distributed and pointing downward, Fig. 35. The number of these perforations is determined by the rule that the combined area should equal twice the area of the air pipe of the agitator. The diameter of the perforations should not exceed three eighths of an inch.

For the treatment of certain chemicals lead pipes have to be used, Fig. 32. The pipes rest on lead supports to give clearance between the pipes and the bottom of the tank, so that the air can blow against the bottom of the tank, thereby keeping the solution in motion.

In some cases it is preferable to perform the agitation with a mixture of air and carbon dioxide, the latter gas being easily obtainable from flue gases. A special agitator designed for this

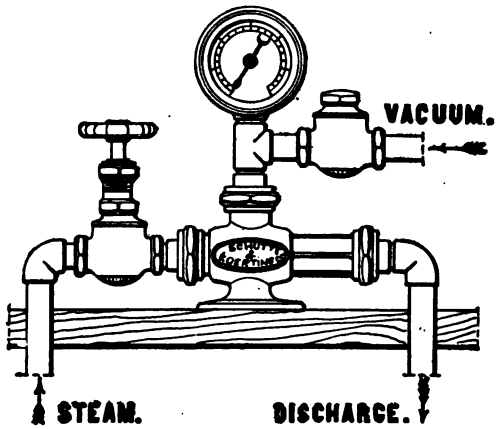


FIG. 30A. STEAM-JET LABORATORY EXHAUSTER.

purpose, the duplex steam-jet agitator, is shown in Fig. 33. *S* is the steam pipe, *C* the inlet for the air containing carbon dioxide or an admixture of other gases, *R* the inlet for the atmospheric air. The two suction branches *C* and *R* can be partly or fully opened,

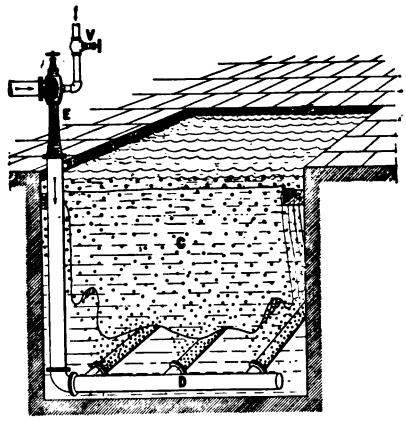


FIG. 31. AGITATOR IN TANNERY PIT.

separately or together, by means of the regulator. The suction branch *C* is connected to the flue of a furnace, while the opening *R* communicates with the atmosphere. According to the position of

the regulator, the liquid is agitated by a mixture of air and carbon dioxide or by carbon dioxide exclusively.

In some cases it is desirable to exclude in the process of agitation the carbon dioxide perfectly, even the amount contained in the

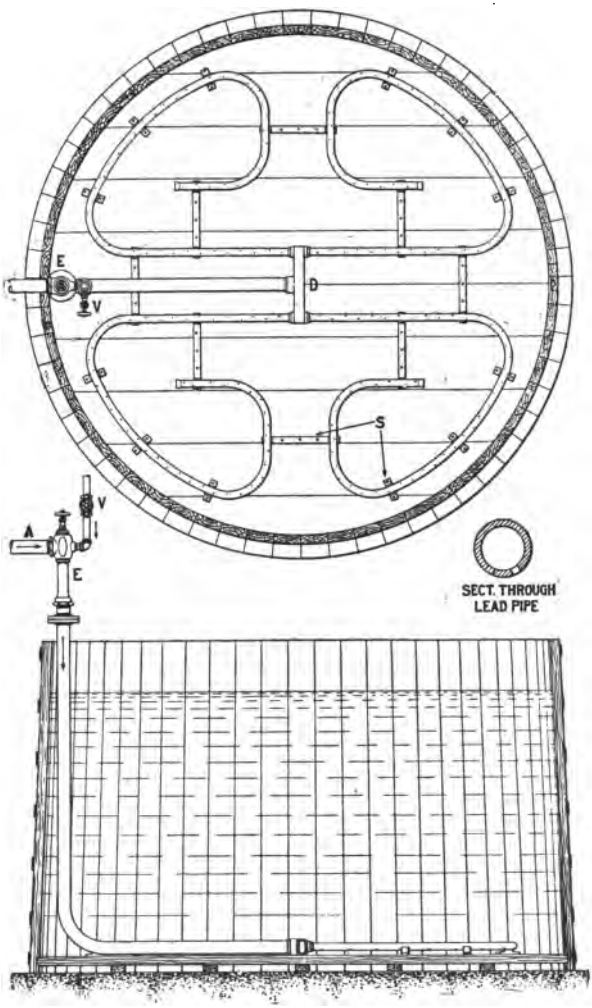


FIG. 32. AGITATOR IN CHEMICAL PLANT.

atmospheric air. With the duplex agitator this is accomplished by closing the tank containing the liquid and connecting the interior of the tank to the suction branch *C* of the apparatus, Fig. 34. It will be readily understood that now the same air is continuously

circulated, whereby the object in view is attained in a most satisfactory manner.

As shown in Fig. 35 the bottom of the tank is usually provided with two slanting boards *HH*, the distributing pipes *L* being arranged about three inches above the center. One air pipe should be installed for every 20 inches of breadth of the tank. For instance, a tank having a width of 28 inches should be provided with two distributing pipes.

FIG. 33. DUPLEX AGITATOR.

STEAM-JET GAS EXHAUSTERS.

The moving power in this exhauster, Fig. 36, is a steam-jet, which issues from a nozzle, traverses a series of larger nozzles and thereby creates a sufficient suction for the gas to overcome the counter-pressure. The regulation of the suction corresponding to the production of gas is effected by a self-acting governor.

This exhauster is simple, economical, efficient, requires no attendance and repair, and is of low first cost. It increases the

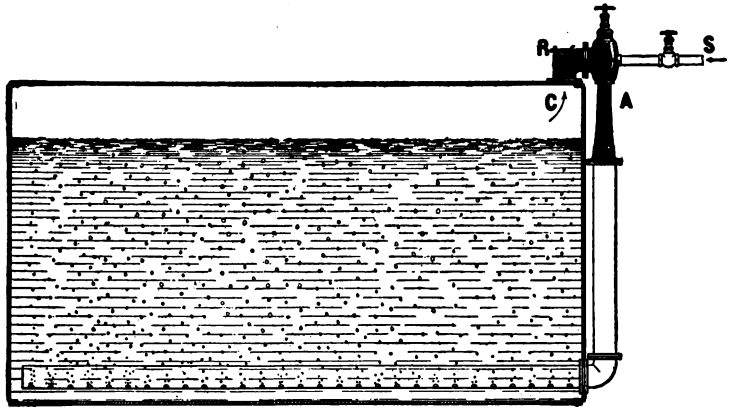


FIG. 34. AGITATOR ON TANK.

quantity of gas produced from one ton of coal, decreases the carbon deposit in the retort, and increases the illuminating power of the gas.

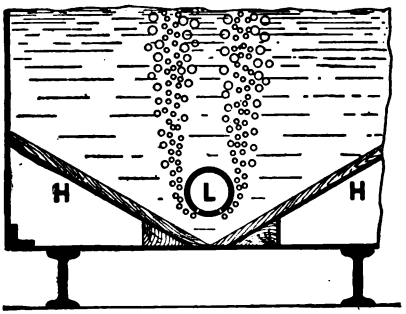


FIG. 35. ARRANGEMENT OF AGITATOR.

FIG. 36. STEAM-JET GAS EXHAUSTER.

In Fig. 37 *D* is the drip, *E* the exhauster, *G* the connection to gas main, *H* the discharge, *S* the steam inlet, *T* the governor, *W* the

hand wheel for regulating the capacity, *CF* the base containing the by-pass to the apparatus.

In gas works this exhauster, which may be attached horizontally, diagonally or vertically, is usually placed on the main, between the

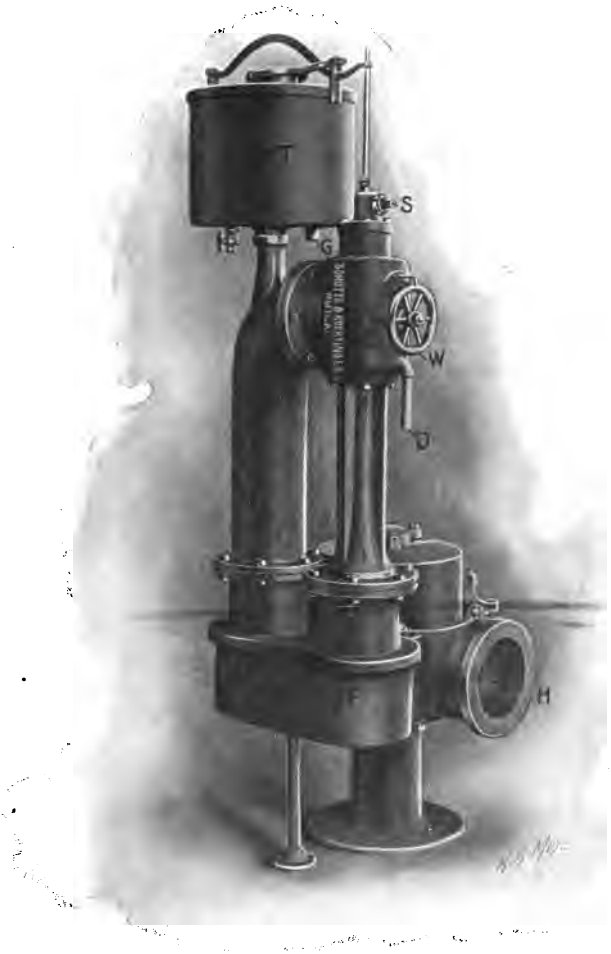


FIG. 37. INSTALLATION OF GAS EXHAUSTER.

main and the condenser or between the scrubbers and the purifier. In the latter case the gas should traverse a sufficient length of the pine line, as to condense the steam before entering the purifiers, or a cooler should be employed. If placed between the condenser and the scrubber, a steam scrubber should be used in connection with

TABLE VI.

Size. No.	Capacity Cubic Feet per Hour.	Size of Pipes.		Size. No.	Capacity Cubic Feet per Hour.	Size of Pipes.	
		Steam.	Exhaust.			Steam.	Exhaust.
1	1,000	¼	2	10	12,000	¾	8
2	1,500			11	15,000		
3	2,000	⅜	3	12	18,000		
4	3,000			13	20,000		
5	4,000	½	4	14	25,000	1	10
6	5,000			15	30,000		
7	6,000	½	6	16	40,000	1¼	12
8	8,000			17	50,000		
9	10,000			18	60 000		

the exhauster, in order to utilize the condensed steam for scrubbing. A steam trap should always be fixed on an elbow in the steam line, right before the exhauster, as otherwise the moisture

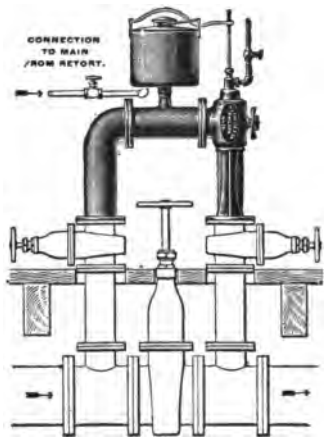


FIG. 38. CONNECTION OF GAS EXHAUSTER.

FIG. 39. HARD LEAD BLOWER.

of the steam would interfere with the working. The steam pipes should be blown out with steam, before connection is made. The governor should be placed as close to the exhauster as possible. The vacuum pipe under the bell of the governor may be attached to the gas main at any place between the retorts and the exhauster, Fig. 38. Table VI. gives the capacities.

LEAD STEAM-JET BLOWERS AND EXHAUSTERS.

The blowers and ventilators of this type are used to overcome and to produce respectively a counter-pressure or rarefaction of from

one half to 6 inches of water. They are constructed, as is shown in Fig. 39, with side inlet for gas and are provided with removable end covers in order to be conveniently accessible, without the necessity of disturbing connections except the small steam pipe. De-

TABLE VII.

Size No.	Capacity in Cubic Feet per Hour.	Size of Connections in Inches.		Inches.		
		Steam.	Gas.	*A*	*B*	*C*
00	8,000	½	4	14⅜	7	4
0	16,000	½	5	20	8⅝	5¼
1	30,000	½	6	33	5¼	5¼
2	60,000	¾	8	44½	8⅛	6¾
3	120,000	1	10			

pending upon the application the steam nozzle is lined with platinum or some other satisfactory metal or with hard rubber.

Installations are shown in Figs. 40 and 41. In Fig. 40 *A* is the steam supply pipe, *B* the blower, *C* the gas supply pipe and *R* the

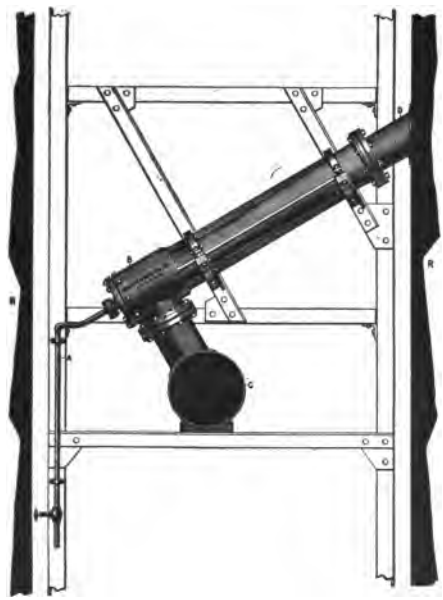


FIG. 40. INSTALLATION OF LEAD STEAM-JET EXHAUSTER.

chambers. In Fig. 41 *A* is the tank, *E* the blower, *R* the chamber and *S* the stop valve. Dimensions and capacities are given in Table VII., Fig. 42.

The lead exhausters and compressors of this type, Fig. 39, are constructed for a rarefaction up to 20 inches of mercury and above, or for a counter-pressure up to one seventh the steam pressure.

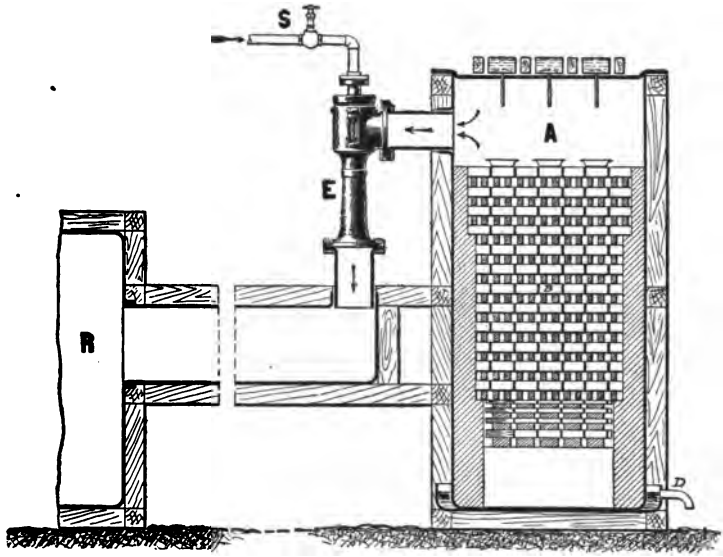


FIG. 41. INSTALLATION OF HARD LEAD BLOWER.

Table VIII. (Fig. 43) gives the capacities and dimensions of these exhausters and compressors. An application of an exhauster for drawing sulphurous acid gas through a liquid is shown in Fig. 44. *E* is the exhauster, *F* the sulphur furnace and *G* the tank.

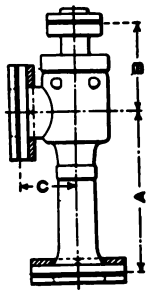


FIG. 42. BLOWER.

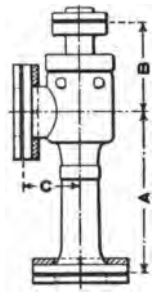


FIG. 43. EXHAUSTER.

These instruments may be arranged horizontally or vertically, discharging upwards, downwards or horizontally. Traps in the suction and discharge pipe are to be avoided.

TABLE VIII.

Size, Inches.	Capacity of Air per Hour, in Cu. Ft.	Diameter of Pipes in Inches.		Inches.		
		Air.	Steam.	*A*	*B*	*C*
1	1,000	1	⅜	4	2⅝	2½
1½	2,000	1½	½	6	4½	3⅛
2	4,000	2	¾	8¼	5⅜	3½
2½	6,000	2½	1	10½	6¼	3⅞
3	12,000	3	1¼	12	6¾	4¼
4	18,000	4	1½	15½	7¾	5⅛
5	27,000	5	2	19	8½	5½
6	35,000	6	2	22¼	9¼	6½
7	48,000	7	2½			
8	60,000	8	3			

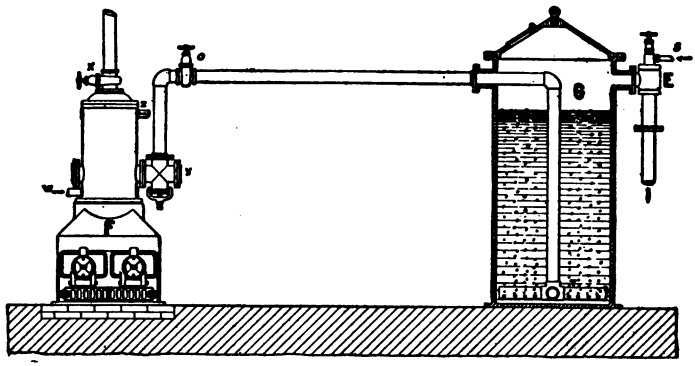


FIG. 44. SULPHUROUS ACID PLANT.

WATER-JET EXHAUSTERS AND COMPRESSORS.

The exhauster works by a water jet and creates nearly absolute vacuum even with low-pressure water, for instance with a head of 15 feet. However, the capacity regarding the volume of the gases moved increases with the pressure. In Fig. 45, which shows such an exhauster, *D* is the discharge, *V* the vacuum and *W* the pressure water. Another construction is shown in Fig. 46. The letters have the same meaning as in the preceding cut.

TABLE IX.

Vacuum (Inches Mercury).		5	10	15	20	25	29½
Size.	Water Pressure in Lbs.	Time in Seconds.			Time in Minutes.		
No. 4	10	10	30	60	2	4	10
	20	5	15	30	1	2	5

FIG. 45. WATER-JET EXHAUSTER.

These exhausters are used in connection with stills if a distillation under vacuum is desirable, especially in cases where the gases evolved attack metals or where the vapors have to be condensed at the same time. They are reliable, simple and cheap. Fig. 47 shows a connection to a still.

FIG. 46. WATER-JET EXHAUSTER.

Of about the same construction is the water-jet vacuum pump, which is actuated by a jet of water, having a pressure of 10 pounds or more. The object of this pump is the creation and maintenance of a vacuum to assist filtration, percolation, evaporation, distillation and condensation, either by removal of air or by condensing the vapors. Fig. 48 shows the application for filtration. All connections on this pump are one quarter inch and must be made air-tight. When the pressure of the water is varying, a check valve has to be inserted in the vapor pipe.

The capacity of this pump at 20 pounds water pressure is one third of one cubic foot displacement per minute of air at atmospheric

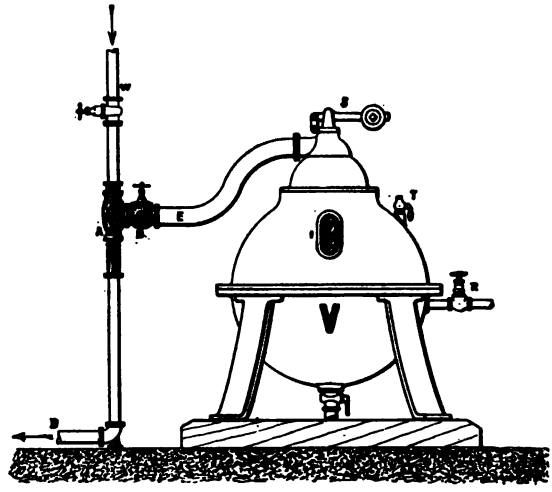


FIG. 47. STILL.

pressure. The rate of displacement increases with increasing vacuum, as shown in Table IX. This table also contains data re-

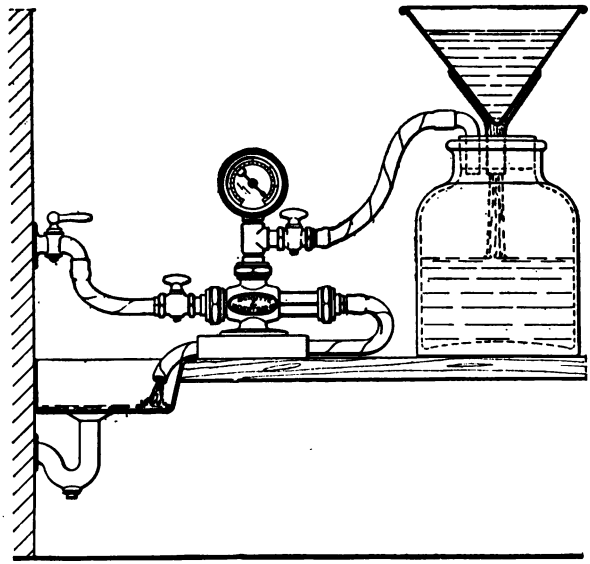


FIG. 48. VACUUM PUMP.

garding the different degrees of rarefaction in a one-gallon vessel and in a stated time.

The water-jet exhausters are widely used in connection with vacuum boxes of paper machines, as in the production of tough

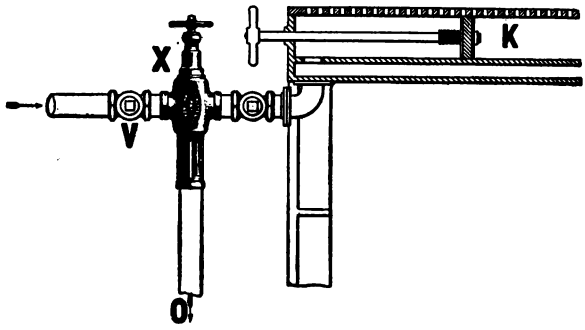


FIG. 49. EXHAUSTER ON PAPER MACHINE.

paper the water has to be drained completely. This application is shown in Fig. 49. The exhauster *X* is attached to the vacuum box as shown and water is supplied to the exhauster under constant pressure. The pressure is produced by means of an overhead tank. The discharge pipe *O* should be sealed. When the exhauster is in use both cocks should be widely opened. Regulation is effected by operating the hand wheel of a spindle. For the extraction of a small quantity of water under a high vacuum the spindle has to be wide open. For extracting a large quantity of water under low vacuum the spindle should be almost entirely closed.

FIG. 50. WATER-JET AIR COMPRESSOR.

The water-jet air compressor shown in Fig. 50 is used for soldering purposes, forges and in laboratories. The upper part of the reservoir *C* is provided with a water-jet air compressor, the water entering through opening *E*. The air is sucked in through the

small perforations L. In the reservoir the water is separated from the air and is discharged through a syphon pipe. The air is discharged at P. For soldering work the apparatus is made to give a pressure of 4 inches of water with a water pressure of 45 pounds, which is the usual city water pressure.

Water-Jet Primers.

In places where steam is not available water-jet primers, which are just as reliable and simple, are successfully used. The main applications are: priming syphon pipes, centrifugal pumps, long suc-

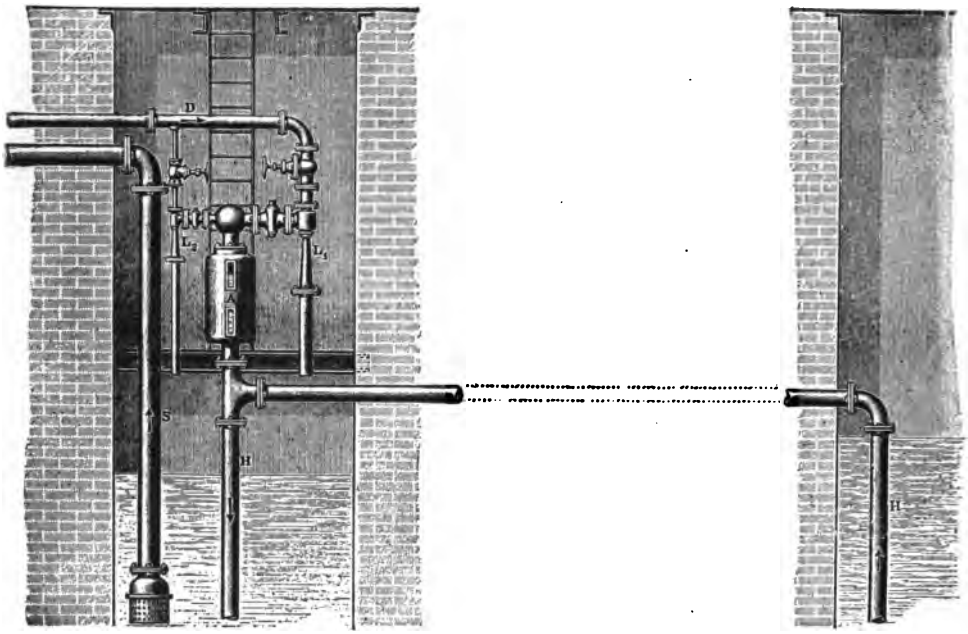


Fig. 51. Water-Jet Primer.

tion pipes of piston pumps and air vessels. Installation is made at the highest place of the piping to be evacuated and one or more exhausters are connected to it. If two instruments are used they should be selected of different capacities. The larger one should be used to fill the pipe line or system when starting, and the smaller one for the continuous evacuation of the air vessel. The rising and falling of the water level can be watched through an indicator glass provided on the air vessel. If the volume of the system to be evacuated is not very large, only one exhauster is generally used

both for filling and evacuating. In such cases it is advisable to make the air vessel sufficiently large.

Table X. gives the capacities of these instruments.

Fig. 51 shows the application of the apparatus in a syphon pipe. *A* is the air vessel, *D* the water pressure pipe, *H* the syphon pipe

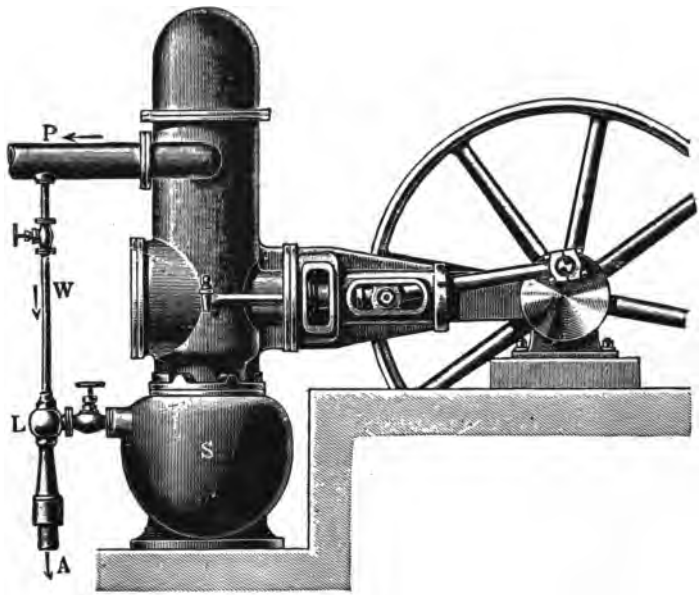


FIG. 52. PRIMER CONNECTED TO ENGINE.

TABLE X.

Size.	Capacity of Air Drawn in at a Vacuum of 15 ft. of Water in cu. ft. per Hour.	Size of Pipes.		
		Water-pressure Line at 45 lbs.	Air Pipe.	Discharge Pipe.
1	70	1	¾	1¼
2	100	1¼	1	1½
3	200	1½	1	2
4	380	2	1¼	2½
5	570	2½	1½	3
6	900	3	2	3½

and *L* the water-jet primer. Fig. 52 shows the exhauster directly connected to an engine: *L* is the water-jet primer, *P* the pressure pipe, *S* the suction vessel and *W* the water-pressure pipe for the primer.

These primers work satisfactorily with 30 feet water pressure and overcome a suction up to 25 feet. If they are installed with

centrifugal pumps, the discharge pipes of the latter have to be equipped with gate valves, which are vacuum-tight. In order to start the primer, first the water valve and then the air cock is opened. For stopping, this operation is reversed. If the head of

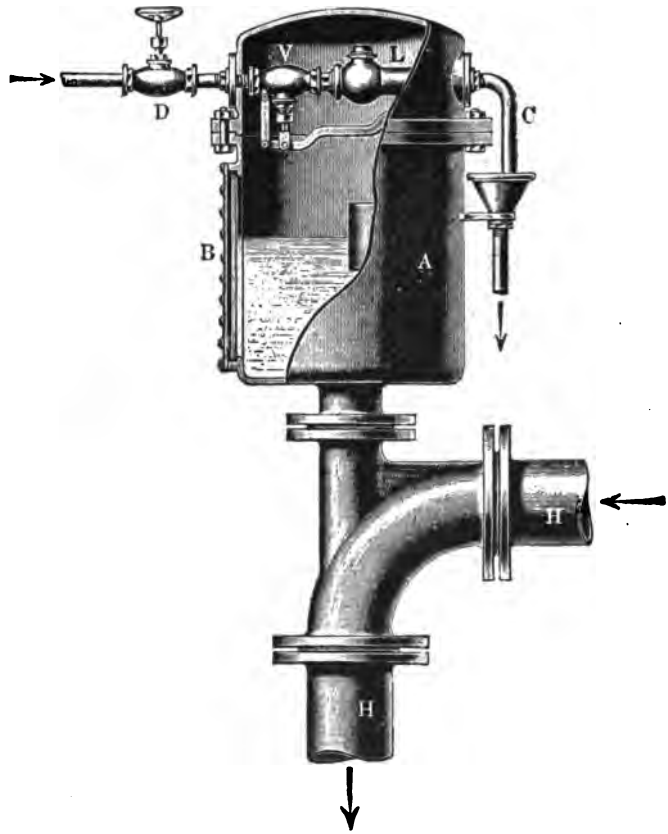


FIG. 53. AUTOMATIC PRIMER.

the water used is less than 60 feet, the discharge pipes of the primer have to be water sealed.

A type of water-jet primer that works automatically is shown in Fig. 53. The jet apparatus is installed inside of the vessel, and the pressure water is started automatically by a float, when the water level drops, evacuating until the water has risen to the proper height. Then the water supply is shut off automatically by means of a float-actuated water-pressure valve. In the illustration *A* is the air vessel, *C* the pressure-water discharge, *D* the water-pressure

line, H the syphon pipe, L the water-jet primer and V the automatically operated valve.

Water-Spray and Compressed-Air Ventilators.

The motive power in the water-spray ventilator is a fine water spray, produced by water which is forced under pressure through a spray nozzle. The water issues from the nozzles in the form of a cone and strikes against the inner walls of the apparatus. The efficiency of the apparatus is as high as 50 per cent.

Fig. 54. Water-Spray Ventilator.

The air is considerably cooled in its passage through the cone of spray, and is moistened and washed at the same time. These features of the apparatus are very valuable. As an example of the cooling effect of these ventilators it may be mentioned that by an apparatus supplied for an underground engine-room, the temperature of the room was reduced from 96 to 76° Fahr., the temperature of the water being 66°.

A standard apparatus, as shown in Fig. 54, is provided with a water separator, but the construction may be changed to suit local conditions. W is the water inlet, E the air inlet, A the air discharge and U the water overflow. The installation of a ventlator blowing air into a coal mine is shown in Fig. 55. The capacities are given in Table XI.

The jet ventilators worked by compressed air are especially constructed for ventilating mines exposed to fire damps. These ventilators have the great advantage that the quantity of air delivered

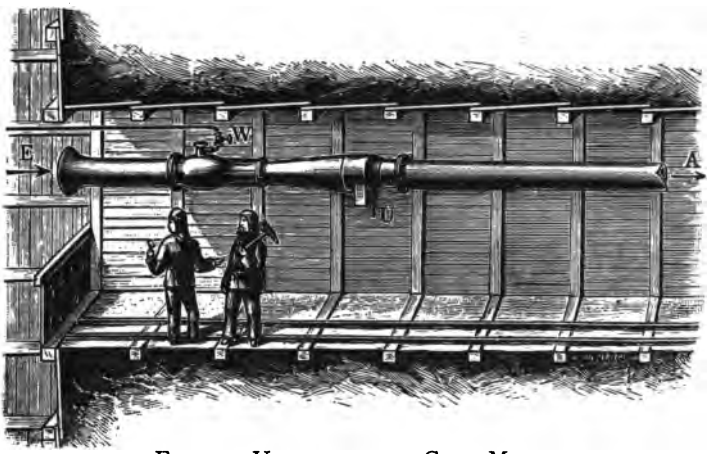


FIG. 55. VENTILATOR IN COAL MINE.

TABLE XI.

No. of Apparatus.	Diam. of Air Conduit. Inches.	Air Delivered in Cu. Ft. per Hour with 90 lbs. Water Pressure.	Diam. of Water Pipe. Inches.
1	6	8,000	½
2	8	16,000	½
3	12	32,000	¾
4	16	50,000	1
5	20	75,000	1¼
6	24	100,000	1½
7	28	150,000	1¾

can be easily and rapidly increased or decreased without stopping their action. They can be arranged either to blow the air forward or to exhaust it, as shown in Fig. 56, or to exhaust and to blow at the same time, as shown in Fig. 57, the efficiency being the same in both cases.

TABLE XII.

No. of Apparatus.	Inside Diameter of Air Conduits. Inches.	Air Delivered per Minute in Cubic Feet.		Inside Diameter of Compressed Air Pipe. Inches.
		With Short Air Conduits.	With Air Conduits of 300 Feet.	
1	6	600– 750	450	¾
2	9	1200–1500	900	1
3	12	2400–3000	1800	1½
4	16	4500–5500	3300	1¾

If the apparatus is to be connected to zinc pipes, the pipe is slipped over it at *e*, Fig. 58. When wood conduits are used, the

ventilator is put into them, without any other support. At the proper point the conduit is closed by a piece of board provided with a hole, which corresponds to the opening handle.

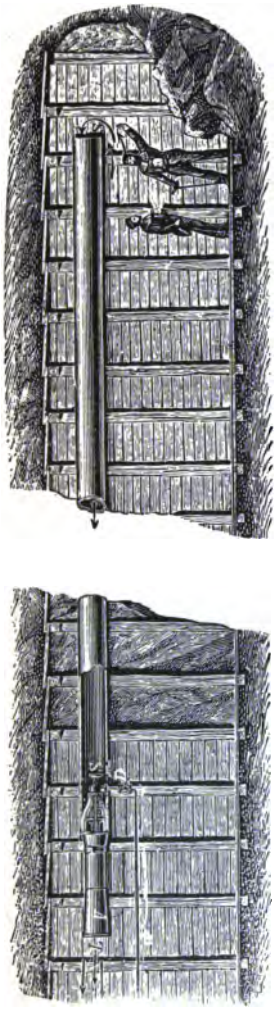


FIG. 56. INSTALLATION OF VENTILATOR.

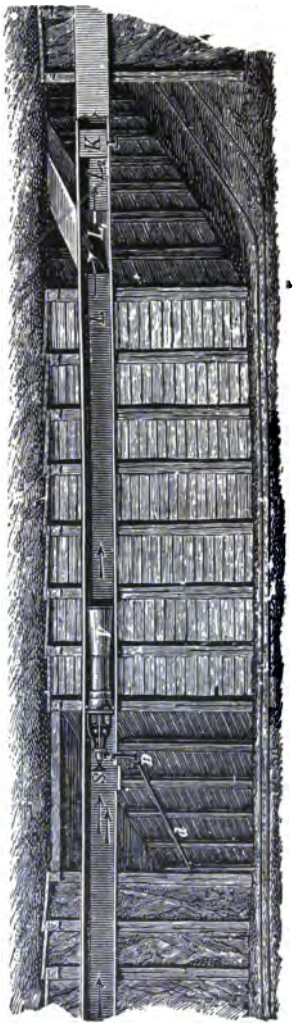


FIG. 57. INSTALLATION OF VENTILATOR.

Table XII. gives the capacities at 45 pounds pressure of compressed air and widely opened spindles. If the pressure is less, the capacity is decreased.

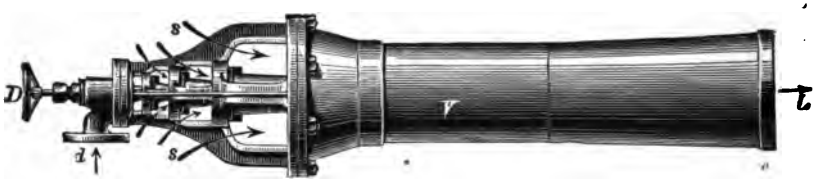


FIG. 58. COMPRESSED-AIR VENTILATOR.

FORGE BLOWERS AND AIR-JET BLASTS.

The compressed air forge blower which supplies air for combustion to stationary and portable forges is rigidly connected to the latter and the compressed air is conveyed to the blower usually by means of a hose. The force of a small jet of compressed air draws a large volume of air from the atmosphere and forces it under the grate. Regulation of the air is effected by a cock installed on the blower. The standard type consumes 2.3 cubic feet of compressed air per minute, expressed in atmospheric pressure. In Fig. 59 *A* is the inlet for compressed air and *D* the discharge. Fig. 60 shows

FIG. 59. FORGE BLOWER.

the installation on a portable forge: *A* is the hose, *B* the forge blower, *C* the cock.

The air-jet blast is also used to advantage for cleaning castings in erecting shops, foundries, metal refineries, etc. When erecting a machine it is of importance to have the parts to be put together

entirely clean. Compressed air is an excellent means to accomplish this result and air-jet blasts, such as shown in Fig. 61, are conveniently used, as they are always ready for operation as soon as they are connected to a compressed-air line. The apparatus shown in the illustration consists of several concentrical nozzles. One of these is used for sucking in the necessary amount of liquid

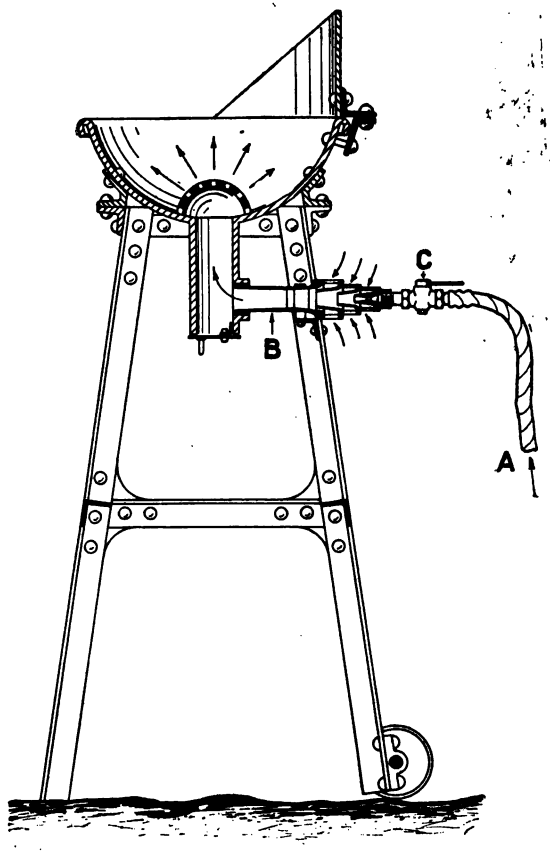


FIG. 60. PORTABLE FORGE.

for moistening, connection to the pot containing the liquid being made by a rubber hose connected near the handle of the apparatus. The nozzle *g* is provided with perforations *h*, through which the atmospheric air is drawn. A spring valve installed on the handle is set in operation by pressing a push-buttom. If no liquid is to be used the hose is simply taken out of the tank containing the liquid.

Fig. 62 is an illustration showing the successful use of air-jet

blasts in foundries to remove the loose sand by blowing out the mould. This method does not require as much care as the cleaning by means of hand bellows and is naturally much more economical as the use of direct compressed air. For moistening the moulds the air-jet blast is also the most economical and most convenient means.

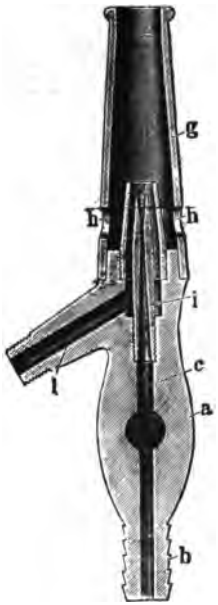


FIG. 61. AIR-JET BLAST.

PATENT GAS COMPRESSORS.

These gas compressors are constructed for compressing acid gases which, if compressed by piston pumps, attack the piston rings, stuffing boxes and other moving parts of the pump, thereby causing bad leaks after short use. The patent gas compressor has no moving parts and is driven by compressed air, the compressing action being performed by means of a neutral liquid, which acts as a piston. The kind of liquid used depends on the nature of the gas to be compressed. For compressing chlorine, for instance, concentrated sulphuric acid is used.

These compressors are of very simple construction, are not subject to wear and tear, cannot get out of order and, being auto-

FIG. 62. AIR-JET BLAST IN FOUNDRY.

matic, do not require any attention. They are successfully used for compressing chlorine or other acid gases to high pressure and for

liquefying same; for leading acid gases through liquids; for forcing gases into digesters or other receptacles, in which reactions under pressure are to be effected; for moving chlorine, etc., through pipe lines, drying towers, etc., avoiding the inconvenience connected with the arising of pressures in the generators; for drawing in gases and delivering same at any pressure required.

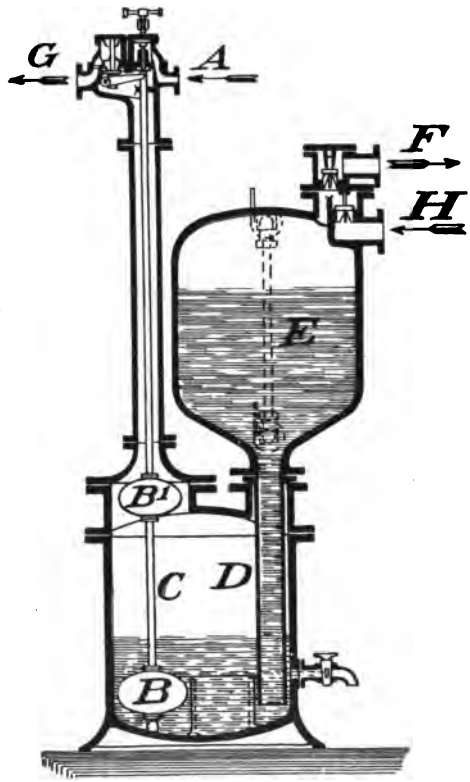


FIG. 62A. GAS COMPRESSOR.

The compressor is shown in Fig. 62A. Compressed air enters through valve *A*, which is alternately opened and closed by the action of the float *C*, which consists of balls *B* and B^1. When valve *A* is open, the liquid is pressed by compressed air from *D* into *E*. The liquid in *E* is therefore rising and the chlorine, which, as will be described below, has been previously sucked into *E*, is compressed and, after reaching the pressure desired, forced through valve *F* into the delivery pipe.

As soon as the surface of the liquid in *D* reaches the lower part of ball *B*, the float drops, valve *A* is closed and valve *G* opened, whereby the compressed air is caused to escape. Simultaneously the liquid runs from *E* back into *D*, creating a vacuum in *E*, whereby the chlorine is drawn through valve *H* into *E*. When the upper part of the ball B^1 is reached by the liquid, the float is raised by the buoyancy. Thereby valve *A* is opened again, valve *G* is closed and the compressing action begins again.

The compressor works thus automatically and regularly as long as compressed air is available. If the supply of compressed air suddenly ceases, the compressor stops working without coming out of order, starting up again automatically as soon as the compressed air reaches again the necessary pressure.

In an installation comprising only one compressor, the suction and compression are alternately performed. In order to effect continuous operation two compressors are coupled together in a suitable manner.

SECOND PART.

TRANSPORTATION OF LIQUIDS.

Double-Tube Injectors.

The injector which is mainly used for feeding boilers is a combination of two jets, the lower jet being proportioned for extreme

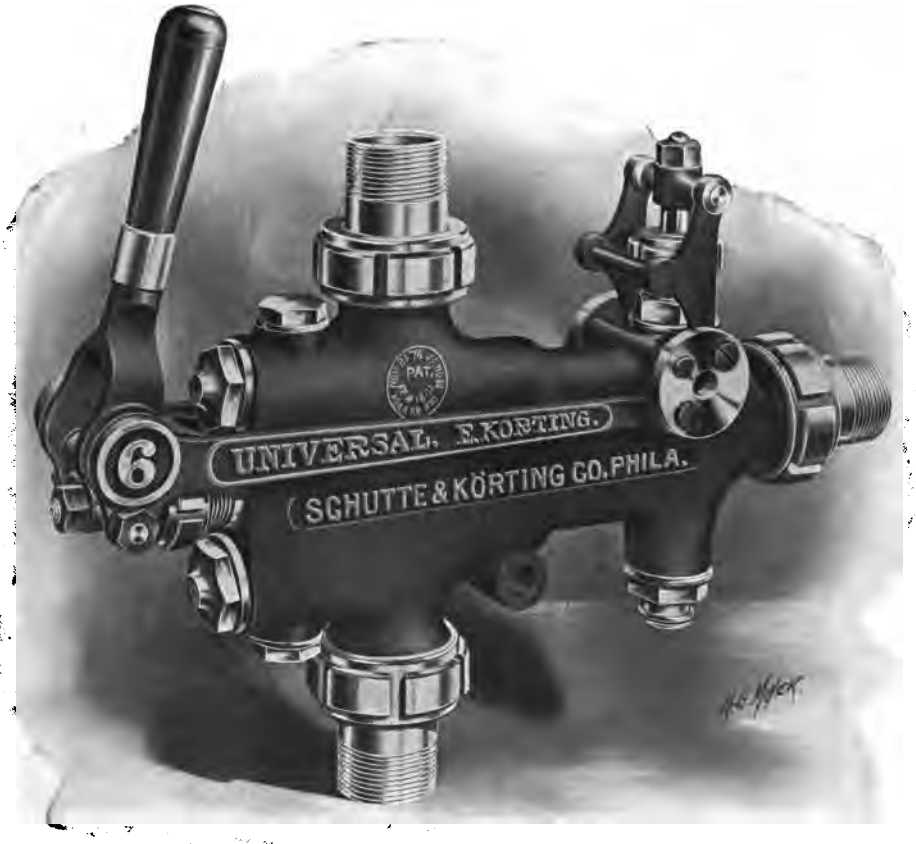


Fig. 63. Double-Tube Injector.

temperature, for quick and strong action and for a maximum capacity of suction. Discharge is made into the upper jet, where an additional strong impulse is imparted to the water, to carry it into

the boiler. The pressure of the lower jet corresponds to the steam pressure and the latter must be according to the requirements of the upper or forcing jet. The varying volume of the steam at varying pressure insures the proper working of the instrument at high as well as low steam pressure. Increased pressure admits of increased high temperature. On account of its automatic features the injector works with the same strong and positive action under varying pressures of steam even at very high temperatures.

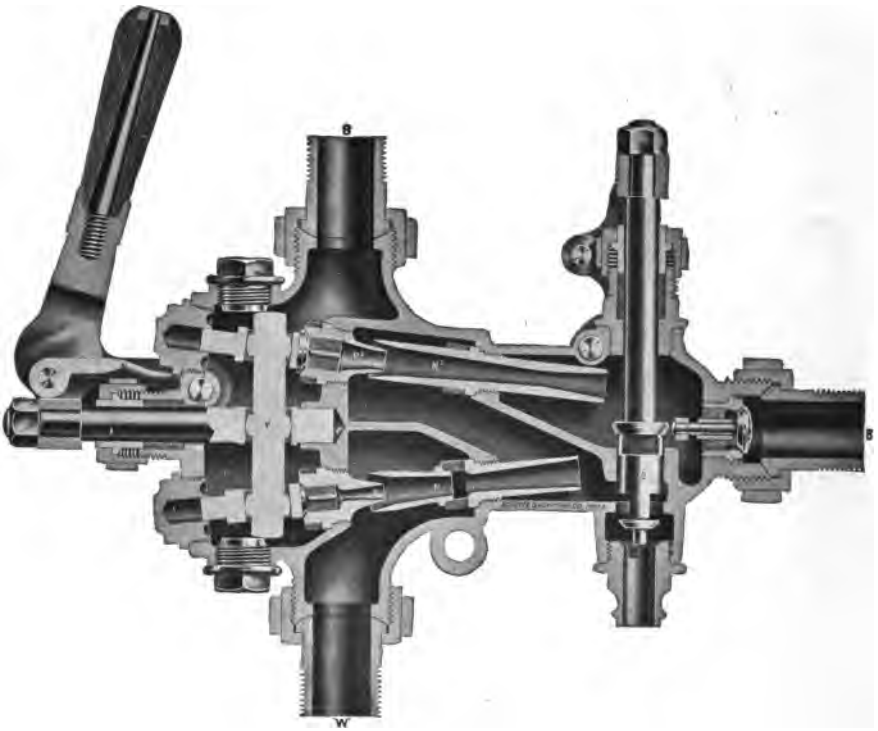


FIG. 64. SECTIONAL VIEW OF INJECTOR.

Fig. 63 gives the outside view, Fig. 64 the sectional view of a double-tube injector. *B* is the discharge, *N* the lower water nozzle, N^1 the upper water nozzle, *O* the overflow valve, *P* the lower steam nozzle, P^1 the upper steam nozzle, *S* the steam supply and *W* the suction.

The capacity of the injector should be 30 per cent. in excess of the maximum capacity of the boiler. Hence the required injector capacity may be said to be about 40 pounds or five gallons of water

per horse-power hour of the boiler. For intermediate capacities the next larger size is to be selected, according to Table XIII.

If the capacity of the boiler is unknown, it may be approximately figured from the following data (all dimensions being in feet):

Flue boilers, one or two flues . . . diam. × length : 3.

Tubular boilers, upright . . . sq. of diam. × height : 4.

Tubular boilers, horizontal . . . sq. of diam. × length : 5.

Tubular, locomotive type . . . sq. of diam. of waist × length over all : 6.

Water tube boilers . . . total heating area in sq. feet : 10.

Grate area . . . area in square feet × 3.

Coal burned per hour. . . number of pounds : 3½.

The results from these formulas express the evaporating capacity of a boiler in horse powers based on the evaporation of 30 pounds of water per horse-power hour.

TABLE XIII.

Size. No.	Size of Iron Pipe.	Steam 50 Lbs.		Steam 100 Lbs.		Steam 150 Lbs.		Size of Copper Pipe, O.D.
		Gals.	H.P.	Gals.	H.P.	Gals.	H.P.	
00	⅛	33	7	48	10	60	12	¼
0	¼	83	17	101	20	112	22	⅜
1	⅜	112	23	143	30	180	36	½
2	½	172	35	210	40	232	46	⅝
3	¾	278	56	338	70	397	80	⅞
3½		398	80	472	95	547	110	
4	1	533	108	622	125	720	150	1⅛
5	1¼	675	136	802	160	922	190	1½
6		825	165	990	200	1125	230	
7	1½	1072	215	1372	280	1612	320	1¾
8		1388	280	1800	360	2115	430	
9	2	1688	340	2100	420	2475	500	2¼
10		2025	400	2438	500	2850	570	
11	St. & D. 2 Suc. 2½	2530	500	3050	625	3515	712	St. & D. 2¼ Suc. 2¾
12	2½	3000	600	3638	750	4252	850	2¾
14	3	3867	780	4635	930	5500	1100	3¼
16		5025	1000	6075	1200	7000	1400	
20	4	9000	1800	10840	2200	12525	2500	4¼

The injector takes water of 80° Fahr. under suction of 6 feet; with water of somewhat higher or lower temperature, or with a lift a few feet higher or lower, or with water flowing to the injector, the capacity varies about 5 per cent. This, however, has not to be considered, as the injectors are built with a liberal margin. But, if the suction height is considerably greater (say from 10 to 16

feet), then the next larger size has to be used. The limit of the height of suction in all sizes except No. 0 and 00, is 20 feet, but it is preferable not to exceed 16 feet. The limit for size 0 is 15 feet, for 00 10 feet. The limits of the feed-water temperature at 6-feet suction are with a steam pressure of 100 pounds 150°, with 130 pounds 140°, with 160 pounds 130°. For a suction greater than 6 feet the limit of temperature decreases.

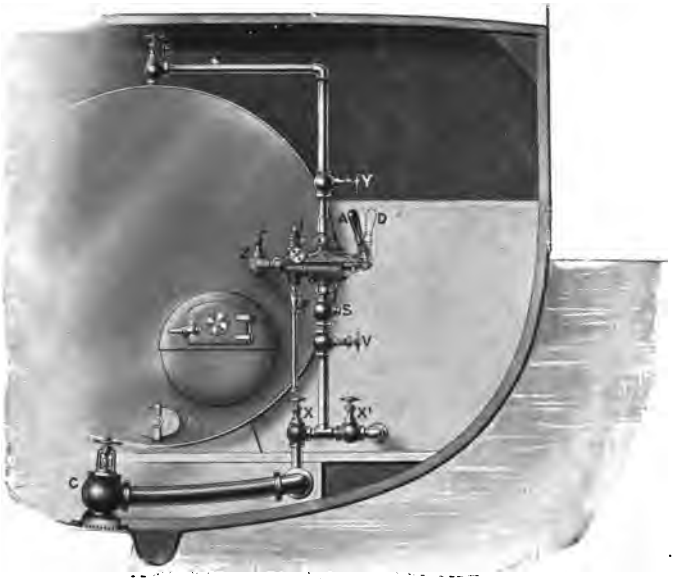


FIG. 65. INJECTOR ON STEAMSHIP BOILER.

The attachment on a steamship boiler is shown in Fig. 65, the general attachment in Fig. 66. *S* is a dirt stop, which has a strainer attached to cap for convenient removal and cleaning. It should be always used for the smaller sizes and in all cases where the water is not clear. *X, Y, Z* are stop valves, *C* is a check valve and *F* a drip funnel, which is connected to a pipe one size smaller than the injector connection.

To start the injector it is opened with handle *A*. In order to stop it it is shut with handle *A*. The quantity of feed is regulated by valve *X*. The steam valve *Y* from the boiler remains open during working hours, starting and stopping being performed exclusively by operating handle *A*. A slight movement of the lever from

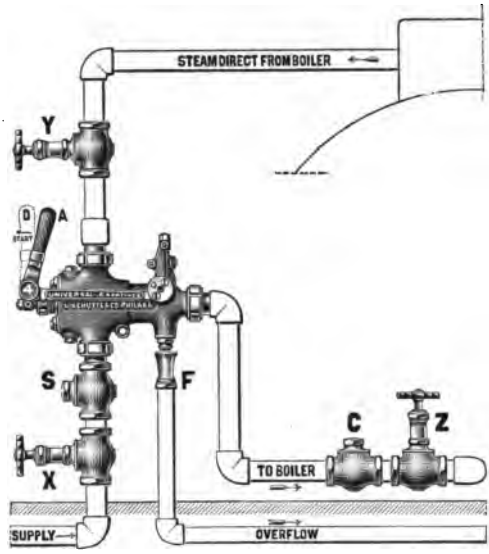


FIG. 66. CONNECTIONS TO INJECTOR.

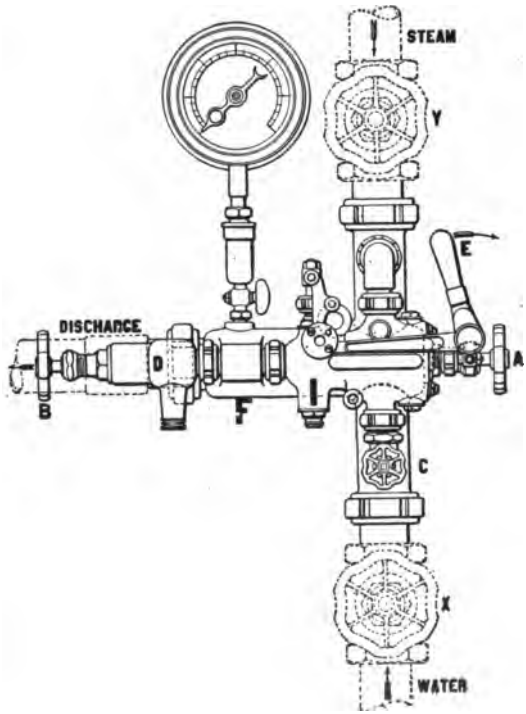


FIG. 67. BOILER TESTER, SIDE VIEW.

A to *D* causes a strong suction and the lever remains at *D* until the water discharges at the overflow; then pull lever wide open in order to feed the boiler.

The boiler tester, which is shown in side view in Fig. 67, in end view in Fig. 68, is built along the same lines as the injector, and is used for filling and testing boilers with hot water for pressures up to three times the regular steam pressure. This instrument is a combination of two machines, one is filled the large machine *F* is shut off, boiler and a smaller one to overcome a high counter-pressure. When the boiler is filled the large machine *F* is shut off, and the small high pressure machine *I* is started to apply the pressure. This small machine has just sufficient capacity to make up for possible leaks in the boiler under test, any excess above this being discharged through the automatic overflow safety valve *D*. This valve is loaded with a spring, which can be set to the desired pressure by means of hand wheel *B* (while looking at gauge). It will then maintain the same pressure while the excess water discharges at the overflow. In order to fill the boiler the main water valve *X* and the main steam valve *Y* are opened. Then valve *C* is closed tight and the steam valve *A* opened. In order to apply the pressure, steam valve *A* is closed tight, water valve *C* opened and the injector *I* started with handle *E*. An air cock, which must be provided on top of the boiler, has to be opened when the boiler is filling and has to be closed again when the boiler is full. *ZZ* are drain cocks. The outside view of such a boiler tester is shown in Fig. 69.

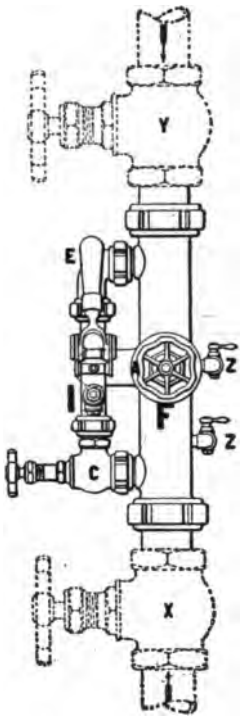


FIG. 68. BOILER TESTER, END VIEW.

Fig. 69A illustrates the pieces comprising the double-tube injector. *1* is the body; *2*, hand lever; *3*, side rods; *4*, connecting fork; *5*, cross head for shaft; *6*, nuts for cross head; *7*, starting shaft; *8*, nuts; *9*, yoke bar; *10*, lower steam valve; *11*, upper steam valve;

12, lower steam nozzle; *13,* upper steam nozzle; *14,* lower water nozzle; *15,* upper water nozzle; *16,* front body caps; *17,* side body caps; *18,* overflow nozzle; *19,* check valve complete; *20,* overflow valve complete; *21,* stuffing box; *22,* fol. for stuffing box; *23,* nuts

FIG. 69. BOILER TESTER.

for stuffing box; *24,* cross head for overflow; *25,* links for overflow; *26,* pin for links; *27,* screws; *28,* bell cranks; *29,* coupling nuts; *30,* pipe unions; *31,* spanner wrench; *32,* socket nozzle wrench; *33,* union for copper pipe.

STEAM-JET SYPHONS.

For purposes where durability, low first cost and simplicity of operation is important or where an increase of temperature is desirable, the steam-jet syphon is the most suitable appliance for moving water and other liquids. This syphon is made of brass or iron body, with brass nozzle. The moving force is a steam jet.

Fig. 70 illustrates such a syphon. These instruments are absolutely reliable, they have no moving parts, show no wear and tear, require no belting, gearing or oiling, a steam connection being all that is necessary for their operation.

The proportions of steam pressure and height of elevation to which these machines are constructed are as follows:

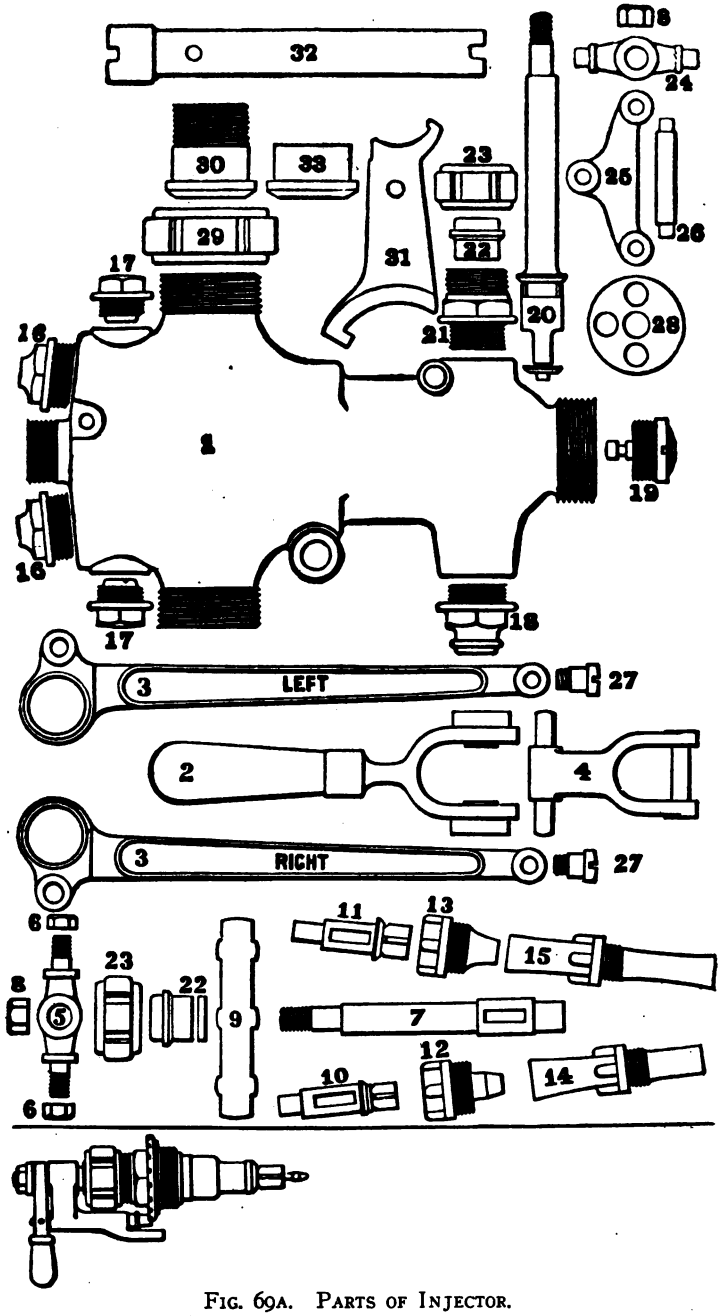


FIG. 69A. PARTS OF INJECTOR.

FIG. 70. STEAM-JET PUMP.

Steam pressure in pounds.....	20	40	60	80	100
Total elevation in feet.....	20	40	60	80	100

The apparatus is best suspended a few feet above the surface of the liquid, but it may be immerged under water, or suspended above at a greater height, within the limit of suction. These limits are as follows:

Steam pressure in pounds.....	20	40	60	80	100
Limit of suction in feet Steam full on....	18	18	15	12	9
Steam regulated	18	20	24	24	24

For elevations of medium height the syphons are made for 24-feet suction and steam turned on full. Where the syphons can be placed under water, or where water flows to them they are built to overcome a total elevation double that given above, and they will take water of 140° Fahr., if it flows to them. For water up to 190° the syphons are especially constructed, as also the syphons which overcome a proportional higher elevation, at the same time maintaining the suction.

The following table gives the steam consumption and the increase of temperature:

Elevation in feet	20	40	60	80	100
Increase in temperature degrees Fahrenheit	15	20	24	28	32
Proportion of steam to water discharged	1/84	1/65	1/58	1/48	1/42

Table XIV. gives the capacities:

TABLE XIV.

Size. Inches.	Diameter of Pipes.		Capacity. Gallons per Hour.
	Suction and Discharge.	Steam.	
½	½	¼	200
¾	¾	⅜	400
1	1	½	700
1¼	1¼	¾	1,100
1½	1½	¾	1,600
2	2	1	3,000
2½	2½	1¼	5,000
3	3	1½	8,000
4	Suction 4 Disch. 3½	2	15,000
6	Suction 6 Disch. 5	3	30,000

On account of its simplicity and reliability the steam-jet syphon is widely used in the industries: In paper mills for lifting chloride solution, milk of lime, thin pulp, etc.; in sugar plants for lifting the sugar juice and milk of lime; in the chemical industries for lifting water, molasses, chemicals, etc.; in electric power stations for emptying foundation pits, fly-wheel pits, etc.; in iron and steel works for lifting water; in railroading for water stations, filling locomotive tenders, etc.; in the navy for bilge purposes and fire emergency pumps; in distilleries and breweries for cleaning cellars and raising mash, etc.

If stoppages should occur in the suction pipe, strainer or in the apparatus, they are easily removed by closing a "shut-off" in the discharge pipe, whereby the steam is blown back and the obstruction cleared.

Fig. 71 shows a syphon removing water from a foundation pit. *D* is the discharge, *S* the syphon. Fig. 72 shows a syphon used on a driven well: *E* is the syphon, *S* the steam supply, *T* the tank. Fig. 73 shows a syphon attached permanently near the source of water. If the instrument is to be used a steam hose connection is made. Fig. 74 illustrates a syphon permanently installed on a locomotive. In order to fill the tender a hose connection is made: The dotted lines show the syphon drawing water from the tender

and discharging it—for extinguishing a fire—through a nozzle provided for this purpose.

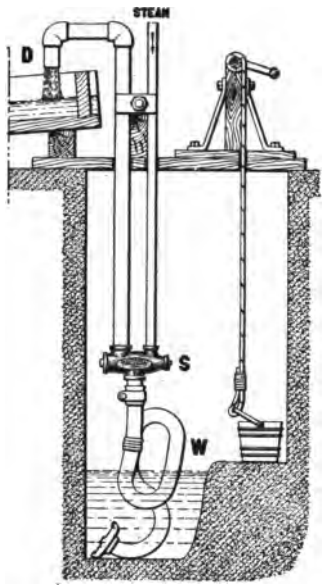


FIG. 71. REMOVING WATER FROM FOUNDATION.

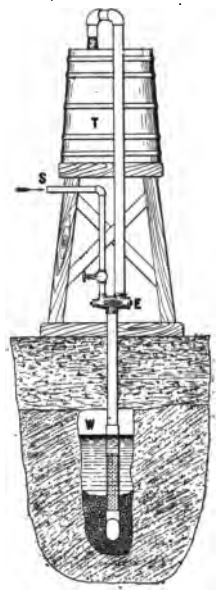


FIG. 72. SYPHON ON WELL.

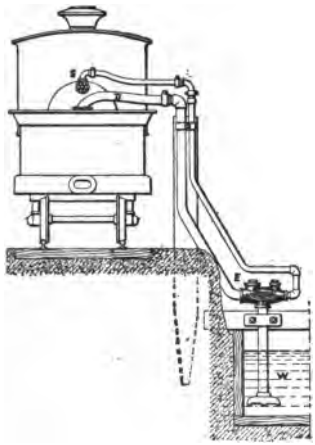


FIG. 73. SYPHON CONNECTED TO WATER SOURCE.

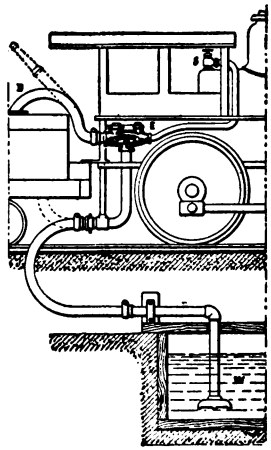


FIG. 74. SYPHON ON LOCOMOTIVE.

The use of this machine on a steamboat is shown in Figs. 75 and 76. The syphon may be placed near the bottom of the boat or at a

higher level (but always within its capacity of suction). While the larger sizes are used as emergency pumps in case of an accident, the smaller ones are used for bilge clearing.

The most extended application of the syphons is found in the chemical industries, such as tanneries, bleacheries, paint factories,

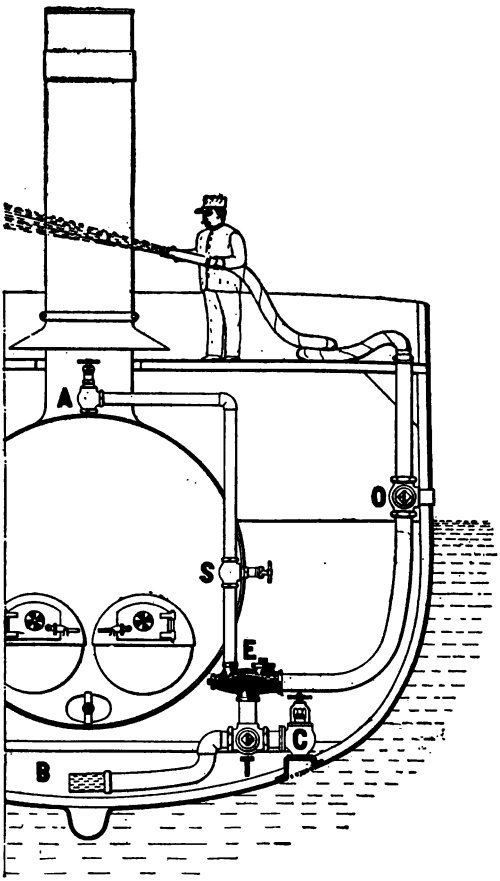


FIG. 75. SYPHON ON STEAMBOAT.

etc., where, in addition to the elevating, a heating of the liquids is desirable. The use of regular pumps is in many of these cases prevented by the nature of the material to be handled, while the syphons, which can be made of lead, porcelain, stoneware or hard rubber, are always applicable. For circulating liquors of any character at a certain regular speed and at the same time keeping the

temperature constant, these machines are also extremely well adapted, as for instance for open or closed kiers. When operating closed kiers the pressure in the steam boiler has to be at least 15 pounds higher than in the kier.

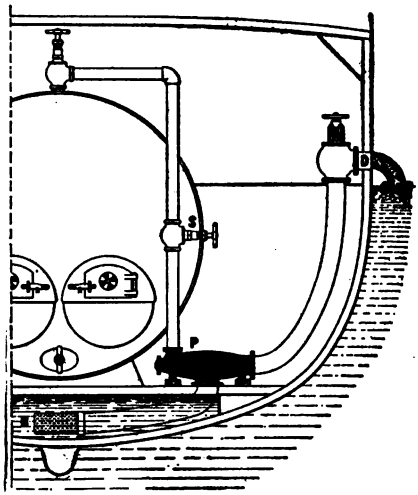


FIG. 76. SYPHON ON STEAMBOAT.

Fig. 77 shows an installation for transferring liquors from pits in tanneries or chemical works. *D* is the discharge, *E* the syphon

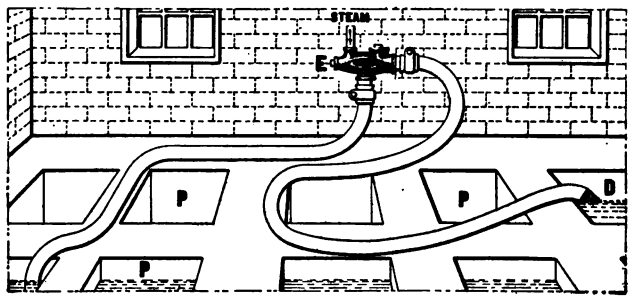


FIG. 77. TRANSFERRING FROM PITS.

and *P* the pit. The application for extracting tannic acid from tan bark by circulation is shown in Fig. 78. *D* is the discharge, *S* the syphon, *U* the steam supply. The operation is as follows: The tank which contains fresh tan bark is filled with water. Steam is now turned on and the syphon discharges on top of the tank, thus

circulating the liquid from the top downward until the extraction is complete. Sometimes this extract is finally circulated through fresh

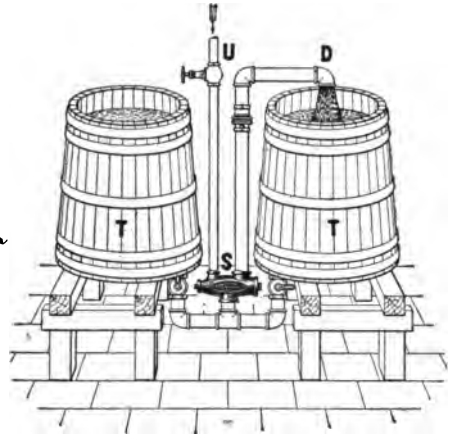


FIG. 78. CIRCULATOR.

bark contained in the second tank. For this purpose the discharge pipe is fitted with a swinging arm as shown in the sketch.

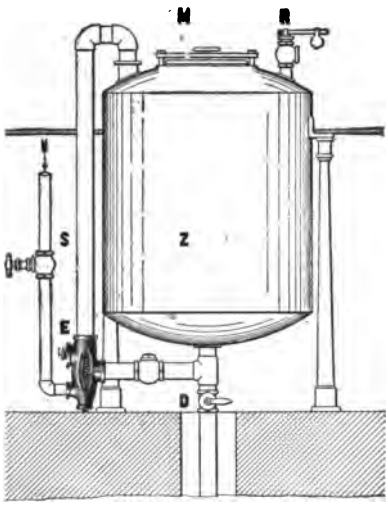


FIG. 79. SYPHON ON CLOSED KIER.

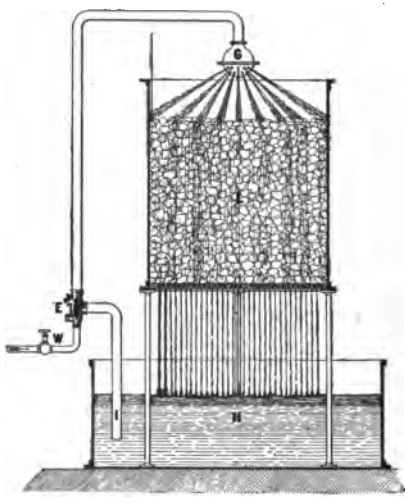


FIG. 80. EXTRACTING CHEMICALS.

Fig. 79 illustrates a syphon on a closed kier. *E* is the syphon, *R* the safety valve, *S* the steam supply and *Z* the kier. The extraction of substances is most successfully accomplished by these syphons.

Fig. 80 shows this application. *E* is the syphon, *H* the tank, *L* the material to be extracted. An installation of a syphon used for lifting alternately from two or more tanks is illustrated in Fig. 81. *A* and *B* are the tanks, *C* the cocks, *S* the syphon and *T* the overhead tank.

The same apparatus built in somewhat different shape, so as to suit the purpose, is used as artesian well syphon. On account of its

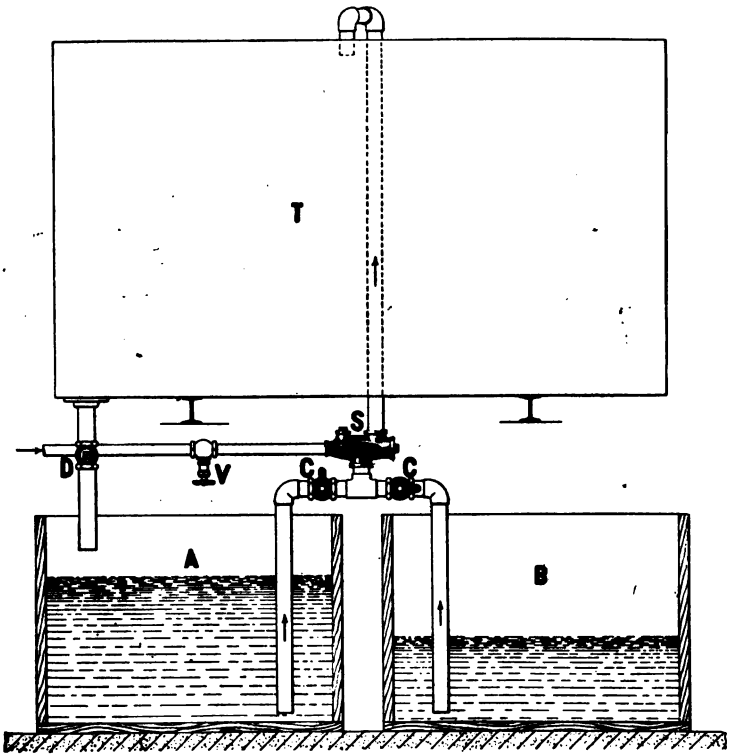


FIG. 81. LIFTING FROM SEVERAL TANKS.

convenient shape even the largest well syphon can be put into a pipe of specified diameter. Provision is made to surround the steam pipe by a covering pipe, or rather that part of it which is under water. Such a well syphon is shown in Fig. 82. *A* is the syphon, *D* the discharge, *E* the steam connection and *S* the strainer. Fig. 83 illustrates an installation.

With steam of 100 pounds pressure the syphon will elevate water to 200 feet. Allowing a reduction of 25 per cent. from boiler

pressure, the total elevation in feet from the syphon to the top of the tank is one and one half the boiler pressure in pounds. With a boiler pressure of 100 pounds, for instance, the lift will be 150 feet.

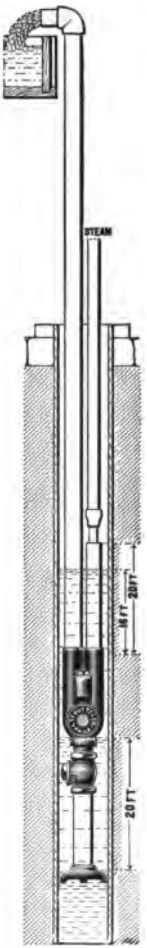


FIG. 82. WELL SYPHON. FIG. 83. WELL SYPHON. FIG. 84. EVACUATOR.

The capacity of the syphon must not be greater than the flow of the well. If the instrument is placed, as shown in Fig. 83, 16 feet under water, with 20 feet of suction pipe, the water in the well can be drawn down 36 feet. If the well does not maintain this level, a syphon of smaller capacity has to be used. In the illustration the syphon is shown 16 feet under water; this distance may be decreased if the well has a higher capacity, and it may be increased up to 25

feet if the well is weak. In order to start the syphon, the steam is simply turned on full; if now the steam should blow through instead of discharging water, the steam valve is closed and kept closed for 5 to 10 seconds. Then the steam is again fully opened. When starting, the syphon must be under water. The capacities are given in Table XV.

TABLE XV.

Sizes. Inches.	Diameter of Pipes					Min. Diam. of Well.	Capacity. Gallons per Hour.
	Suction.	Discharge.	Steam in Covering.	Steam above Covering.	Covering.		
1	1	1	½	¾	1	3½	700
1¼	1¼	1¼	¾	1	1¼	4½	1,100
1½	1½	1½	1	1¼	1½	5	1,600
2	2	2	1¼	1½	2	5½	3,000
2½	2½	2½	1½	2	2½	6½	5,000
3	3	2½	2	2¼	2½	7½	7,000
4	4	3	2½	3	3½	10	14,000

For cesspool cleaning or wherever solid matter passes through the apparatus the machine is made with full openings, clear passages being provided for the liquid. For this machine, which is called evacuator or cesspool pump, two strainers are required, one for the suction and one for the steam pipe. Such an instrument is shown in Fig. 84. *D* is the discharge, *P* the pressure steam and *S* the strainer.

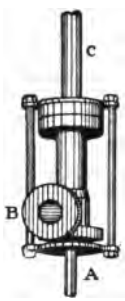
JET ACID PUMPS.

These pumps are built along the same lines as the syphons described in the preceding chapter and are used for lifting acids, alka-

FIG. 85. ACID-LEAD SYPHON.

lies and other solutions by means of steam, wherever a dilution with steam is not objectionable. They are made of lead, in an iron shell, and are provided with a platinum steam nozzle. Fig. 85 illustrates this type. For handling certain materials it is made of porcelain or stoneware instead of lead.

A lead body is used for lifting weak sulphuric acid, sulphurous acid and copper sulphate; a stoneware or porcelain body for tartaric acid, muriatic acid and solution of bleaching powder; a stone-



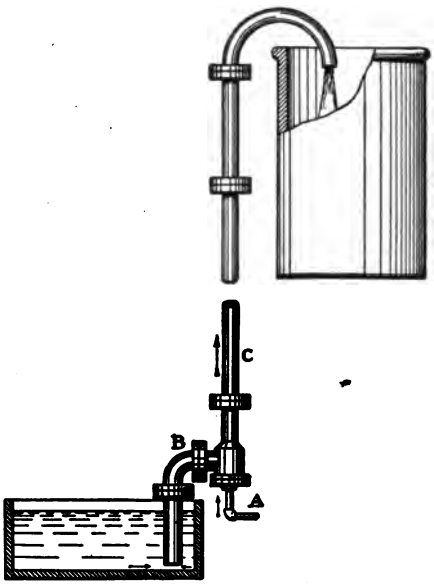


FIG. 86. STONEWARE SYPHONS. FIG. 87.

ware body for strong sulphuric acid and oil of vitriol; an iron body for caustic soda.

The stoneware syphon is shown in Figs. 86 and 87. It is built with a capacity of 600 to 2,400 gallons per hour. The capacities of the lead syphon are given in Table XVI.

TABLE XVI.

Size, Inches.	Size of Pipes.		Capacity Gals. per Hour.	Size, Inches.	Size of Pipes.		Capacity Gals. per Hour.
	Liquid.	Steam.			Liquid.	Steam.	
½	½	⅜	150	2	2	1¼	2400
¾	¾	½	350	2½	2½	1½	3600
1	1	¾	600	3	3	2	5400
1¼	1¼	¾	900	4	4	2½	9600
1½	1½	1	1400				

These capacities are with steam at 60 pounds pressure, 20 feet elevation and acid of 50° Baume. For lighter acid or more favorable proportions of steam pressure and counter-pressure the volume will increase, and *vice versa*.

TABLE XVII.

Pressure of Steam in Lbs.	Strength of Acid in Degrees Baume.					
	10	20	30	40	50	60
	Height in Feet to be Forced					
20	24	22	20	18	16	14
40	48	44	40	36	32	28
60	72	66	60	54	48	42
80	96	88	80	72	64	56

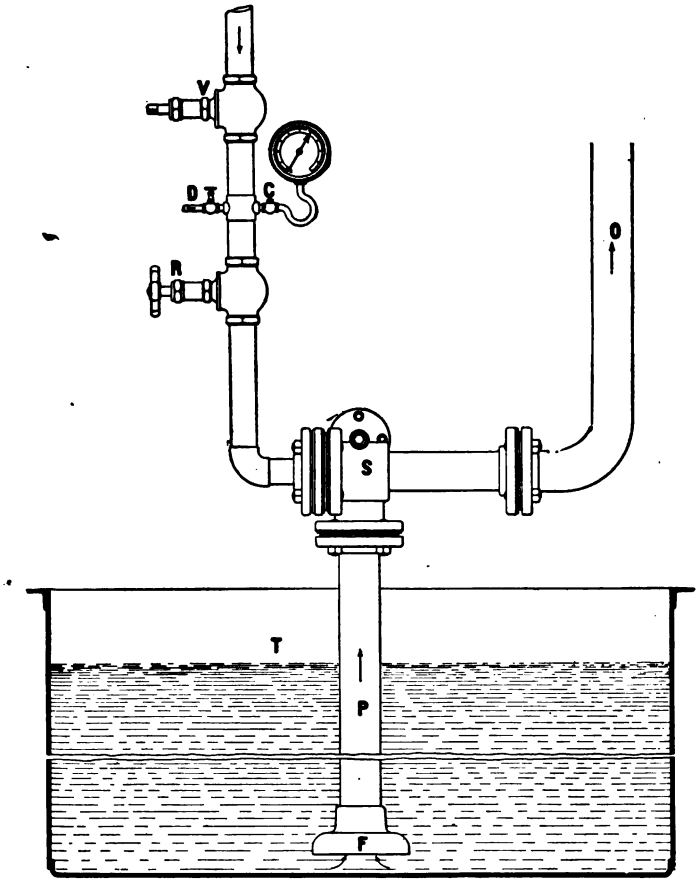


FIG. 88. CONNECTING THE SYPHON.

Table XVII. gives the elevating power of these pumps with different steam pressures for acid of various strength.

Fig. 88 illustrates how the acid pumps have to be connected. *C* is a check valve, *D* a drain, *F* the strainer, *O* the delivery pipe, *P* the suction pipe, *R* a stop valve, *S* the syphon, *T* the tank and *V* a stop valve.

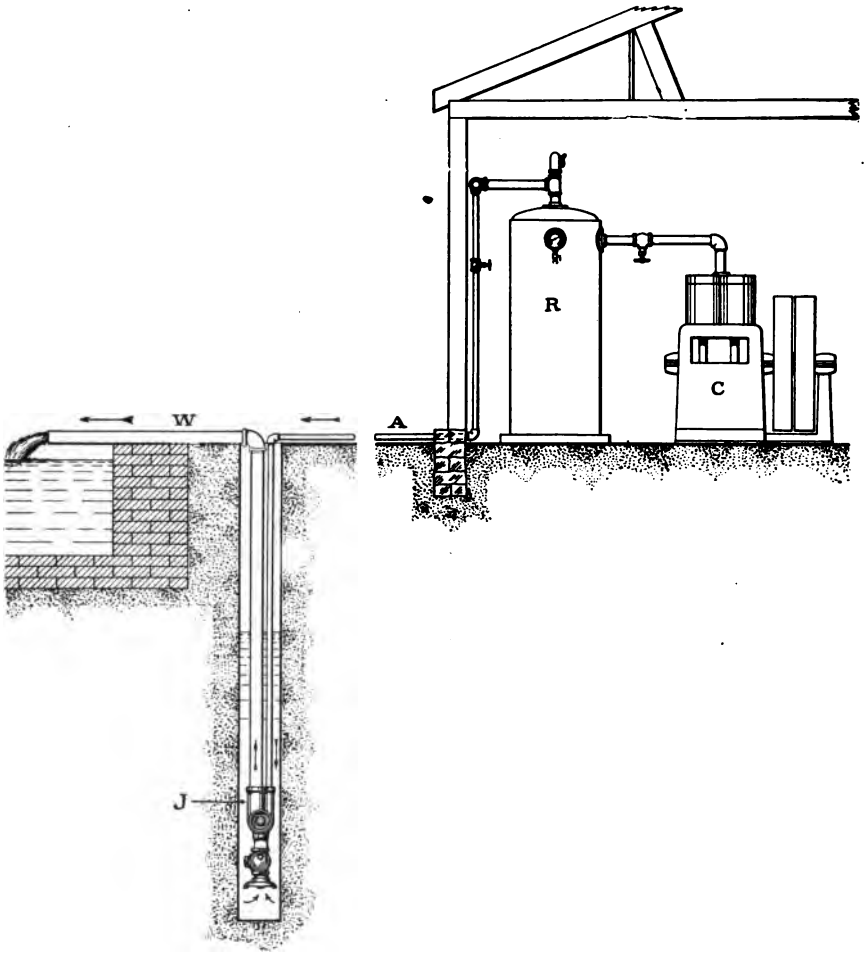


FIG. 89. AIR-JET LIFT.

No lead burning is required for connecting the syphon, as the lead pipe is fitted to the syphon by means of suitable flanges. It is generally to be recommended to fix the syphon one or two feet above the liquid, so that the latter is drawn up and the syphon emptied

when the operation is stopped. The steam pipe should be blown out with high pressure steam before connection is made. If the liquid is dirty a strainer shoould be attached to the suction pipe.

The syphon works best under certain conditions at a certain steam pressure. The latter is ascertained by throttling the steam by means of valve *V*. Then this valve is locked in that position. Valve *R* is used only for operating the syphon. Before starting the syphon, valve *D* should be opened in order to draw off condensation. Care has to be taken that no traps occur in the delivery pipe and that the suction pipe is perfectly air-tight.

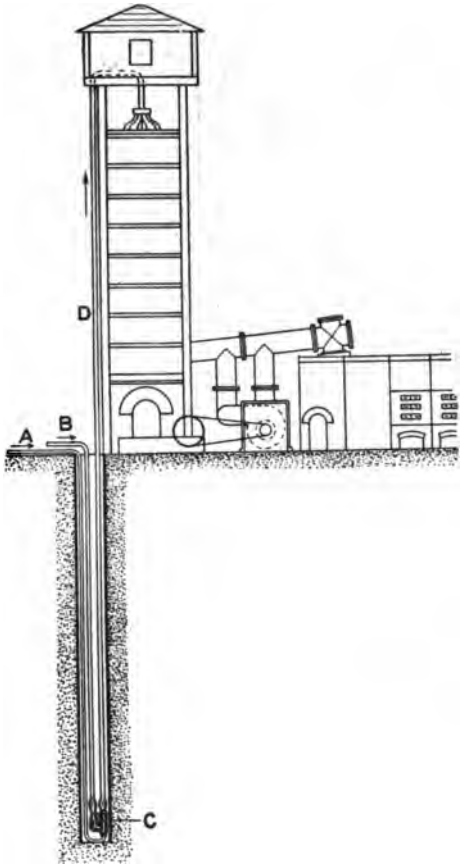


FIG. 90. AIR-JET LIFT IN CHEMICAL FACTORY.

AIR-JET LIFTS.

In all cases where a dilution with steam or water is undesirable the use of steam- or water-jet pumps is impracticable. For these applications the air-jet lift, in which compressed air is used as moving force, is the proper machine.

The working of these machines is as follows: Air is pressed into the lower end of a submerged pipe. The air mixes with the water in the air-jet lift and forms a mixture of air and water, which has a lower specific gravity than water; this causes the column of air and water to be driven upwards by the greater specific gravity of the water column. In other words, the apparatus works through the difference of specific gravity of the two columns.

The arrangement as shown in Fig. 89 consists of the discharge

pipe *W*, the air-pressure pipe *A* and the apparatus proper *J*. The apparatus is so constructed that the air is distributed as uniformly as possible over the area of the water discharge pipe. If the machine is put in a well, a strainer is generally provided at the inlet of the apparatus. The discharge pipe and the air pipe are placed as close together as possible, so that the apparatus can be installed in narrow wells.

FIG. 91. WATER-JET EDUCTOR.

The apparatus has to be installed as deep under the surface of the liquid as corresponds to the height of lift. By opening the valve in the air-pressure line the operation of the apparatus is started and the regulation of the quantity of liquid to be delivered is effected by increasing or decreasing the quantity of compressed air.

These air jets are also extensively used in the chemical industries for lifting acids, alkalies, etc., which necessitate the use of such substances as lead, porcelain, stoneware, rubber, etc., *i. e.*, materials which cannot be used conveniently in the construction of ordinary "mechanical" pumps. The air-jet lift can be made of any material and is therefore well adapted for the handling of corrosive chemicals, the more so as the lift works without "mechanism," works automatically, needs no attention, causes practically no repairs and consumes a very small quantity of compressed air. Further advantages are: The quantity of liquid to be elevated is exactly regulated by regulating the quantity of compressed air to be admitted; the space occupied is very small and in sulphuric acid plants the apparatus is easily installed at the foot of the tower in ordinary sewer pipes, which are sunk in the ground according to the height of the discharge. If the discharge pipes are extended through the top of the Glover or Gay-Lussac towers, the air-jet lift will throw the acid directly into the interior of the towers; if the acid is forced

against a plate inside, an excellent distribution is effected. Fig. 90 shows such an installation. *A* is the air inlet pipe, *B* the acid inlet pipe and *D* the discharge pipe.

Water-Jet Eductors.

The motive power of these pumps is pressure water from city water works, water columns or pressure pumps, passing through the

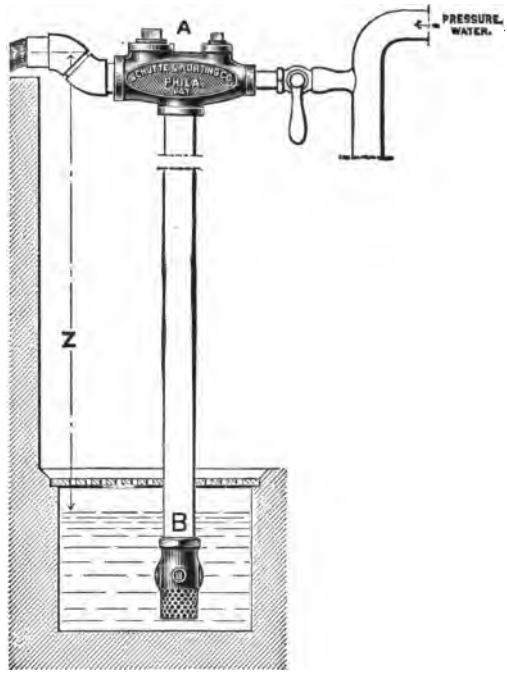


Fig. 92. Draining Cellars.

jet of the apparatus with great velocity. This creates a vacuum and sucks in the water to be lifted, which is carried by the pressure water to the discharge outlet.

Fig. 91 shows such an eductor, Fig. 92 illustrates an installation. *A* is the eductor, *Z* the height of lift. These jet-pumps have the following advantages over ordinary pumps: They have no valves and no moving parts, they are not subject to wear and tear, they cannot get out of order, their first cost is low and their operation very economical, they are noiseless and extremely convenient, where high pressure water is at disposal. They are especially useful for remov-

ing water from pits and quarries, for emptying foundation pits of buildings, engines, etc., for quenching coke, for emptying gas holders, etc.

TABLE XVIII.

Size. Inches.	Diameter of Pipes.			Capacity. Gallons per Hour.
	Suction.	Discharge.	Pressure Water.	
½	½	½	¼	125
¾	¾	¾	⅜	250
1	1	1	½	500
1¼	1¼	1¼	¾	700
1½	1½	1½	¾	1,000
2	2	2	1	2,000
2½	2½	2½	1¼	3,000
3	3	3	1½	5,000
4	4	3½	2	10,000
6	6	5	2½	20,000

Table XVIII. gives the capacities based on pressure water of about 50 pounds and a counter-pressure of about 10 pounds. For such work an equal volume of pressure water is used. When the proportion of pressure to counter-pressure is greater, the volume removed becomes also greater, and *vice versa*. Where the water pressure is varying a check valve should be inserted in the suction in order to prevent back flow.

The pressure in pounds per square inch at the eductor should be not less than two and one half times the elevation in feet. For in-

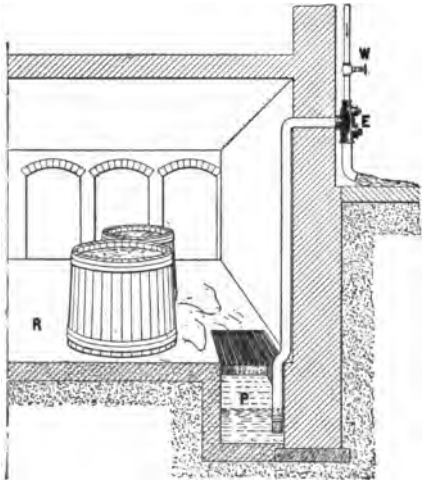


FIG. 93. EDUCTOR INSTALLATION.

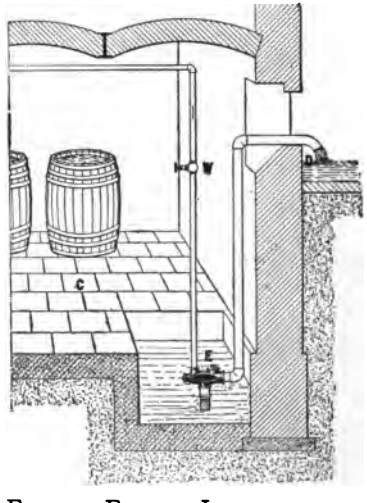


FIG. 94. EDUCTOR INSTALLATION.

stance, a pressure of 25 pounds should be applied if an elevation of 10 feet is desired. The eductor will take water of any temperature up to boiling. It has a strong suction even with low pressure. Where the elevation does not exceed 15 feet, it can be placed at discharge level.

Fig. 93 shows an eductor installed for lifting. *E* is the eductor, *P* the pit and *W* the water-pressure pipe. A non-lifting installation is illustrated in Fig. 94. *D* is the discharge, *E* the eductor and *W* the water-pressure pipe.

For continuous operation the automatic eductor shown in Fig. 95 should be used. This pump turns on the full water pressure when the pit to be emptied is full, and it remains turned on until the pit is empty. Then the water is automatically shut off and remains shut until the pit is full again.

FIG. 95. AUTOMATIC JET EDUCTOR.

Some other installations of water-jet eductors are shown in Figs. 96 and 97. Fig. 96 shows the eductor installed for pumping out a sewer line. This is done in cases where the water cannot flow off on account of an exceptionally high water level of an adjoining river. *D* is the water-pressure line, *E* the eductor, *F* the river, *G* the discharge, *K* the sewer and *S* a foot valve. Fig. 97 shows an interesting application in water works, which obtain their supply through a canal from the river. If in such an installation the level

of the river falls below the canal level, the water works would be without water. The eductor is then used for lifting the water from

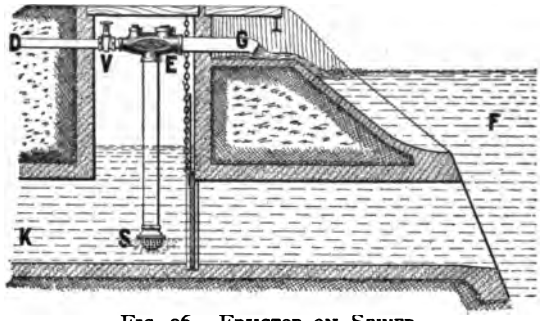


FIG. 96. EDUCTOR ON SEWER.

the river to the canal, so that by this simple arrangement the cost of an expensive pumping machinery is saved. *B* is the main line

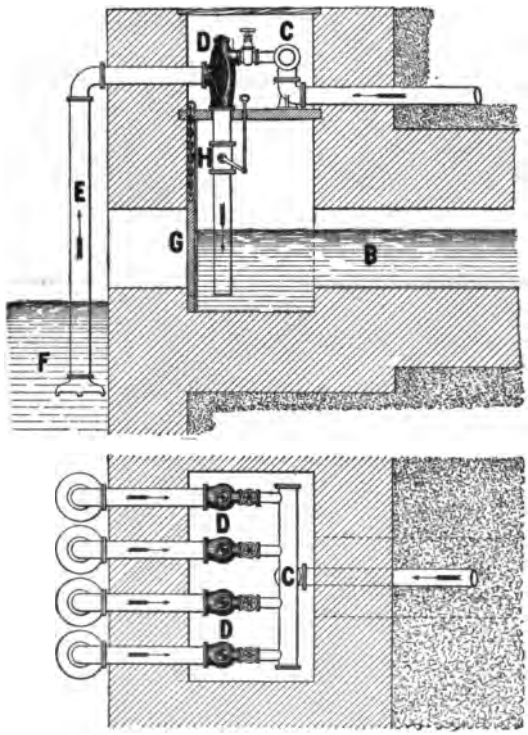


FIG. 97. EDUCTOR IN WATERWORKS.

water works, *C* the water-pressure line, *D* the eductors, *E* the suction pipe, *F* the river and *H* the discharge pipe.

Fig. 98 shows the eductor as it is constructed for use in mines, tunnels, etc. *C* is the cover, *D* the discharge, *P* the pressure water and *S* the suction. Fig. 99 illustrates an eductor operated from the delivery pipe of an underground pump, where by a lack of floor face the use of complicated machinery is prevented. *E* is the eductor, *O* the suction hose and *P* the main pump. Fig. 100 shows a tail pit of a turbine and conveys some idea how, in such a case, the fall of a river can be utilized. Fig. 101 shows an eductor to which the pressure water is supplied by a high pressure pump. *D* is the discharge, *E* the eductor and *P* the pressure line from the pump which creates the water pressure. Fig. 102 shows the eductor installed in a shaft, taking the head water from the surface and discharging it into an upper gangway. From *H* the water flows to the eductor *E* and lifts the water from sump *S*, discharging it into *G*.

Fig. 98. Eductor for Mines.

An apparatus built upon the same principle is the water economizer for fountains, which produce in fountains a display of large quantities of water, with only a very small consumption of pressure water. By using the full city water pressure large quantities of water are moved at a very small expense. If, for instance, the water pressure is 60 pounds and the height of the fountain spray 20 feet, one gallon of pressure water will draw three gallons of water from the fountain reservoir.

In these economizers a jet of pressure water is discharged through a nozzle and forced through the apparatus, thereby sucking in and

constantly using over again the water from the fountain reservoir and lifting the mixture of pressure and re-used water to the height

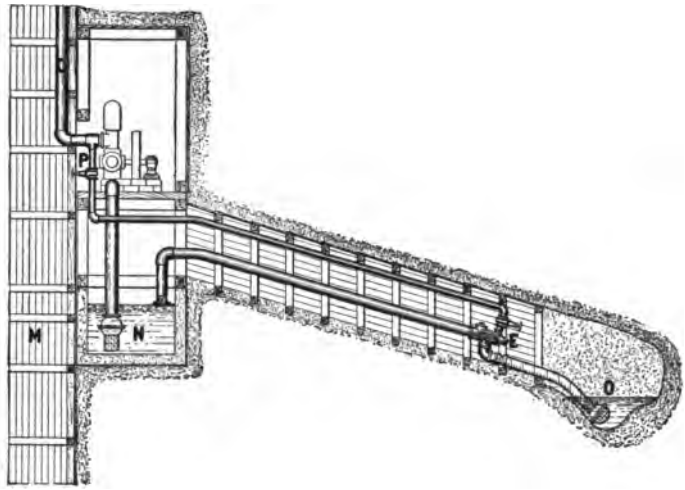


FIG. 99. EDUCTOR FED BY UNDEGROUND PUMP.

desired. The economizers are built either without or with air suction. Fig. 103 shows an instrument without air suction, Fig. 104

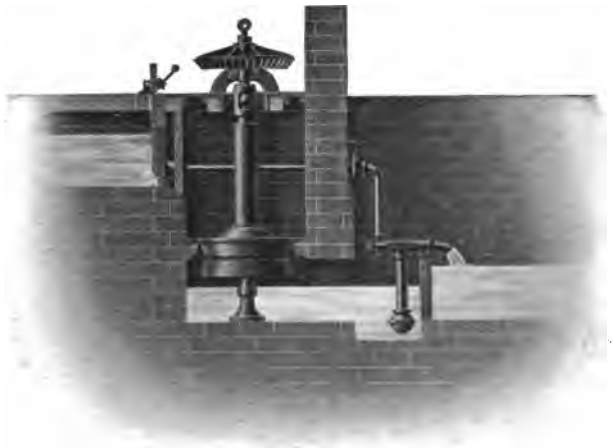


FIG. 100. EDUCTOR IN TURBINE PIT.

one with air suction. *A* is the discharge, *B* the pressure water, *L* the air admission and *W* the suction. The apparatus without air admission is installed on the bottom of the fountain and draws

water only. The apparatus with air admission is installed near the water level in such a way that air can be drawn in through the air openings *L*. These economizers draw air and water, whereby the discharge jet assumes a white and pleasing appearance. Fig. 105 shows an installation without air admission. *A* is the discharge pipe, *D* the pressure water pipe and *E* the economizer.

At this place another instrument may be mentioned which is also used for producing circulation at low expense. This machine is called hydrokineter and is used for effecting a proper circulation of the water in bōilers by means of a steam jet. It draws the cold water from the lower points of the boiler and transports it to the highest water level, so that an intense circulation of the water is accomplished.

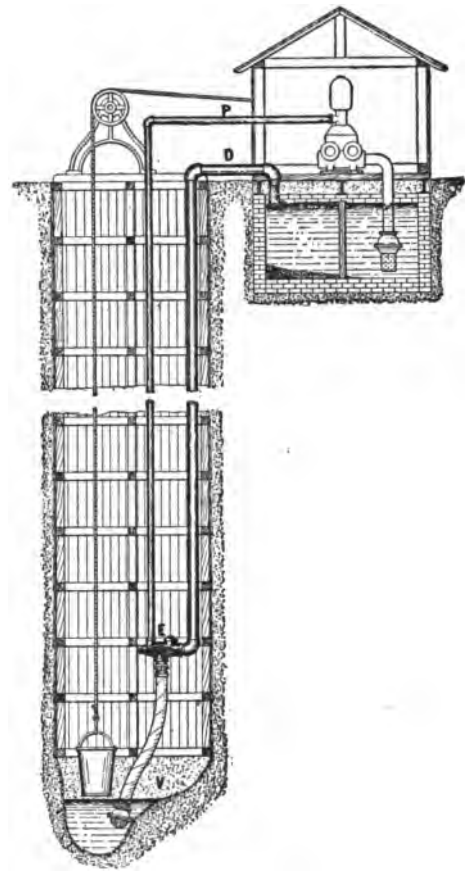


FIG. 101. EDUCTOR FED BY HIGH-PRESSURE PUMP.

A hydrokineter connected to boiler is shown in Fig. 106. *A* is the air cock, *C* a check valve, *H* the hydrokineter, *O* the starting cock and *W* the water stop valve. The hydrokineter must be connected one and one half feet above the highest water level, the suction pipe being connected to the coldest place of the boiler. The discharge pipe is equipped with a check valve and must discharge under water. The steam valve is connected to the hydrokineter and the air cock is inserted at the highest point between the steam valve and the instrument.

The hydrokineter can be put in action immediately when start-

ing up the boiler; it equalizes the difference of heat up to 70° Fahr. It takes steam like an injector and increases the capacity of the boiler.

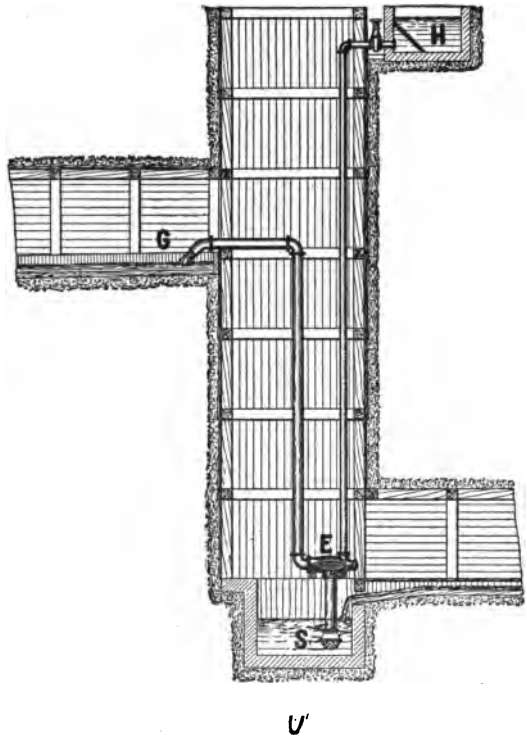


FIG. 102. EDUCTOR IN SHAFT.

Operation.—Open *W* and *A* until water appears, then shut *A*, open *O* and then *S*. Then close *O* slowly.

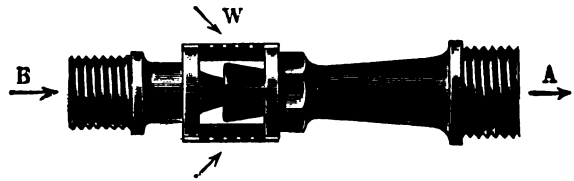


FIG. 103. ECONOMIZER WITHOUT AIR SUCTION.

AUTOMATIC MONTEJUS.

The automatic montejus is used for lifting acids automatically and continuously and takes the place of the acid egg, compared to

which it has the following advantages: It costs less, can be placed anywhere, occupies less floor space, requires no attention, works continuously, requires a much smaller air compressor and has no stuffing boxes. As long as the liquid and compressed air or steam are carried to the montejus it works absolutely safe and reliable. If at any time the supply of compressed air or acids ceases, the apparatus resumes operation at once, when the supply of liquid or of compressed air is started again.

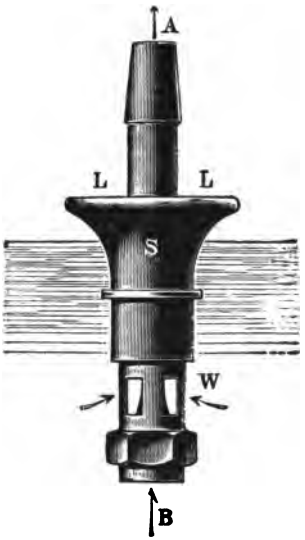


FIG. 104. ECONOMIZER WITH AIR SUCTION.

The working of the machine, Fig. 107, is as follows: The liquid flows to the machine by gravity and enters at *SL* through a check valve. We assume that the tank is empty and that the full weight of the lower float *B* keeps the exhaust valve *DA* open, so that the liquid can freely run into the tank. The liquid will cover the lower

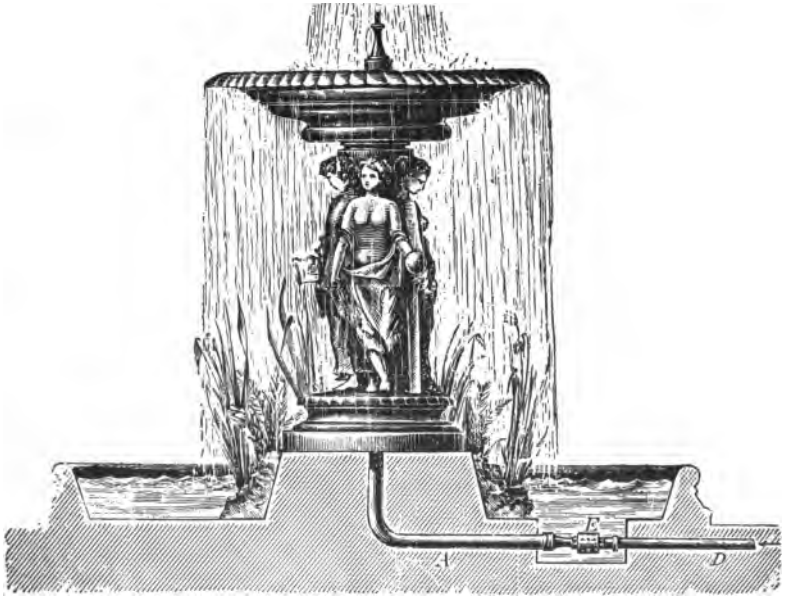


FIG. 105. INSTALLATION OF ECONOMIZER.

float *B* directly, but the buoyancy thus started is not sufficient to open the air valve *EA*. This is accomplished when the liquid reaches the upper float B^1. The combined buoyance of both floats shuts the air exhaust valve *DA*, and opens the compressed-air inlet *EA* and the liquid is now discharged through check valve and discharge pipe *DL*. The level of the liquid falls now immediately under the float B^1, but the weight thus exerted is insufficient to shut the compressed-air inlet valve. This is accomplished after the

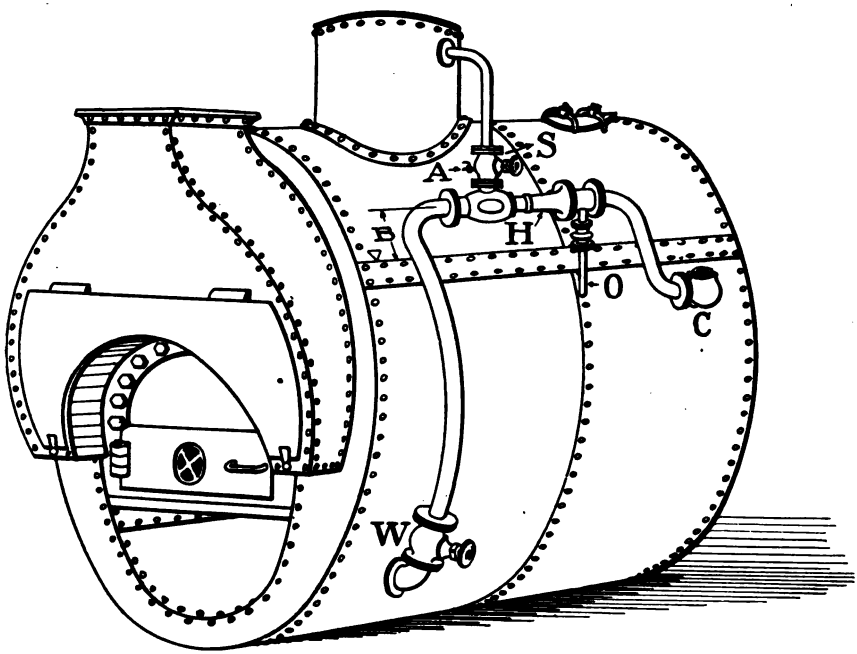


FIG. 106. HYDROKINETER.

liquid has fallen under float *B*, when the weight of the floats is large enough to shut the air inlet valve and to open the air relief valve. Now the conditions are again the same as in the start and the same operation begins again.

As noted in this description, the exhaust air does not escape through the delivery pipe; hence the delivery pipe need not be vertical and can be fitted on the same principle as ordinary water pipes. The pressure of the compressed air or steam can vary between 30 and 70 pounds per square inch without interfering with the regular working of the apparatus.

The great advantage of this montejus is the fact that it works economically also at pressures which are higher than required by the height of the lift and by the specific gravity of the acid. The reason for this is, that the weight balancing the float and rod can be set so that the air inlet valve is closed before the acid level is below the lower float. Now the air expands and discharges the liquid, until the pressure is even with the pressure of the liquid. As in practice it is often impossible to get the correct air pressure for the montejus, this feature is very important from an economical point of view.

FIG. 107. AUTOMATIC MONTEJUS.

The method of installation is shown in Fig. 108. The apparatus has to be installed so that the liquid flows to it. If possible the inlet *SL* should be about 2 feet 6 inches below the bottom of the tank ($O = 2$ ft., 6 ins.). It is also advisable not to fill the feeding tank to a higher level than one foot under the flange below the valve box, as indicated in the illustration.

The minimum pressures required are given in Table XIX. The dimensions of the apparatus with reference to Fig. 108 are given in Table XX. The parts of the montejus, with reference to Fig. 109 are as follows: *1*, Cast-iron body; *2*, cast-iron cap; *3*, cast-iron cap; *4*, Kearsarge gasket; *5*, cast-iron counter flange; *6*, bolts and nuts; *7*, Kearsarge gasket; *8*, cast-iron counter flange; *9*, bolts and nuts;

10, 15, 33, 43, 45, 47, 52, 57, 63, 67, 69 and *74* are Kearsarge gaskets; *11*, O. H. steel clamp; *12* and *14*, studs and nuts; *13*, cast-iron lower section; *16* and *19*, nickel lever; *17* and *20*, nickel pin; *18* and *21*, lead washer; *22*, steel slotted nut; *23*, steel collar; *24*, nickel exhaust valve with rubber seat; *25*, nickel seat; *26*, nickel valve seat; *27*, nickel valve; *28*, cast-iron sleeve; *29*, steel rod; *30*, steel coupling; *31*, cast-iron weight box; *32*, studs and nuts; *34*, cast-iron cover; *35*, cast-iron weight; *36*, steel cap screw; *37*, cast-iron lever; *38*, nickel pivot pin with feather; *39*, cast-iron cap plug; *40*, lead washer; *41* and *42*, clamp set screw; *44*, *46* and *48*, square head bolts and nuts; *49*, lead-covered pipe; *50* and *51*, cast-iron flanged pipe, lead-lined; *53*, square head bolts and nuts; *54*, lead-covered double float; *55*, cast-iron cover, lead-lined; *56*, cast-iron body, lead-lined; *58*, square head bolts and nuts; *59*, cast-iron bottom plug; *60*, cap screws; *61*, cast-iron hand-hole cover, lead-faced; *62*, steel clamp with set screw; *64*, lead pipe; *65* and *68*, square head bolts and nuts; *66*, lead-lined cast-iron tee; *70*, cast-iron counter flanges; *71*, lead-lined cast-iron bodies; *72*, earthenware balls; *73*, cast-iron covers, lead-faced; *75*, cast-steel clamps with set screw.

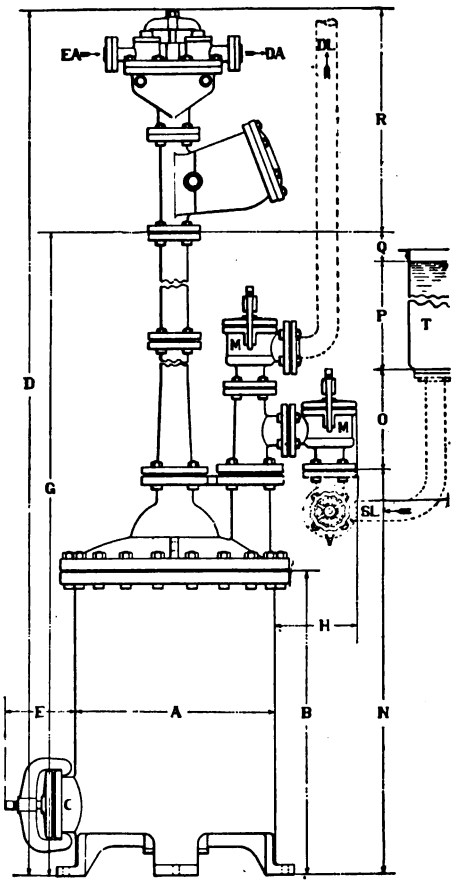


FIG. 108. INSTALLATION OF MONTEJUS.

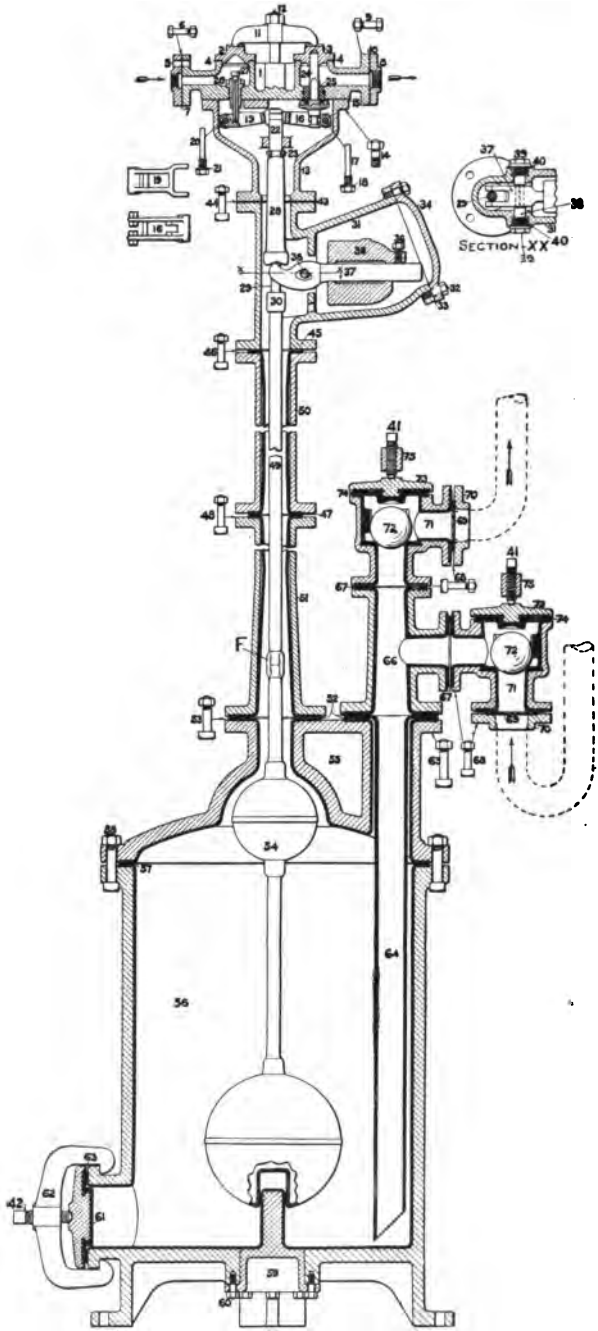


FIG. 109. PARTS OF MONTEJUS.

TABLE XIX.

Height of Lift, Calculated from the Bottom of the Montejus in Feet	SPECIFIC GRAVITY.								
	1, 1	1, 2	1, 3	1, 4	1, 5	1, 6	1, 7	1, 8	1, 9
15	16	17	18	19	19	20	21	22	23
20	18	20	21	22	23	24	25	26	27
25	21	23	24	25	26	27	28	29	30
30	24	26	28	29	30	32	33	34	35
35	27	29	31	32	34	35	36	38	40
40	30	31	33	35	36	38	40	42	44
45	32	34	36	38	40	42	44	46	48
50	34	37	39	41	43	45	47	49	52
55	37	39	41	44	46	48	51	53	56
60	40	42	44	47	49	52	55	57	60

TABLE XX.

Size.	*A*	*B*	*D*	*E*	*G*	*H*	*N*
1	1′ 8″	2′ 3⅝″	10′ 11¼″	8¼″	8′ 9″	9 1/16″	3′ 3″
2	1′ 11½″	3′ 0″	11′ 8¼″	8¼″	9′ 6″	9¾″	3′ 11⅞″
3	2′ 6″	2′ 2″	13′ 8″	10″	11′ 8″	1′ 0″	4′ 4″
4	3′ 3″	3′ 4″	13′ 11″	10″	11′ 11″	1′ 4″	4′ 7″

Size.	*Q*	*R*	Diameter of Pipes.				Weight Including Packing.
			Liquid Inlet Pipes, *SL.*	Liquid Discharge, *DL.*	Air Inlet Pipe, *EA.*	Air Discharge, *DA.*	
1	1′ 0″	2′ 2¼″	1½″	1½″	¾″	1″	1,500
2	1′ 0″	2′ 2¼″	2″	2″	¾″	1″	2,200
3	1′ 0″	3′ 0″	2½″	2½″	1¼″	1½″	3,000
4	1′ 0″	3′ 0″	4″	4″	1¼″	1½″	4,000

THIRD PART.

TRANSPORTATION OF SOLIDS.

Water-Jet Sand and Mud Eductors.

These instruments, which are illustrated in Figs. 110 and 111, are successfully used for cleaning wells, lifting of sand, removing of material when dredging, cleaning of swimming pools, etc. Simplicity in operation and erection and low first cost are the main advantages. The sand eductors are built in two types, one for steam, the other for high pressure water. The steam and water respectively issues through small holes at the lower end of the apparatus,

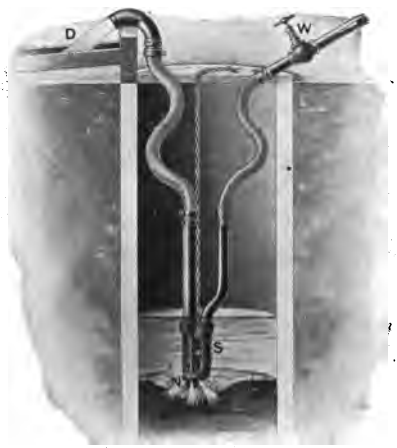


Fig. 110. Sand Eductor.

Fig. 111. Sand Eductor.

Table XXI.

Size of the Apparatus.	Mixture of Water and Sand Delivered per Hour.	Size of Pipes.	
		Steam or Water.	Discharge.
Inches.	Gallons.	Inches.	Inches.
1½	750	1	1½
2½	2600	2	2½
3	3000	2	3
3½	6000	3	3½

and stirs up the solid matter, which is to be lifted. Whether steam or water pressure is preferable depends upon local conditions and upon the nature of the material to be handled. The capacities are given in Table XXI.

Water-Jet Sand-Washing Plants.

In these plants the problem of properly moving the sand is of great importance and we will therefore discuss them at this place.

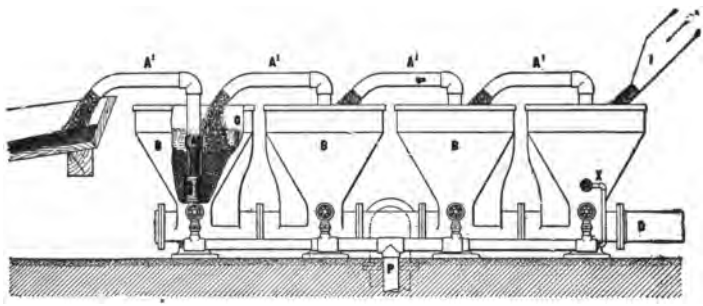


Fig. 112. Sand Washing.

Fig. 112 shows an installation using water-jet eductors. Such a plant consists of a series of iron boxes *B* placed in one or more rows, or in a circle, and in each of the boxes is installed a water-jet eductor *A*. In the first box the sand to be washed is admitted at *I* and is stirred at the same time by means of a clean water jet at *X*. The sand eductor is operated by means of clean water taken from pressure pipe *P* and lifts the sand to the second box. The sand or gravel drops to the bottom of the box, while the water mixing with the dirt, because of the violent stirring, rises and overflows at *O*. In this manner the sand is perfectly washed simply by the use of clean pressure water, without any other mechanical means. Such plants are of importance for water works and for such industries in which the sand has to be freed of clay and iron before being used.

Movable arms are used to put a greater or smaller number of boxes in operation. In a plant of six boxes, for instance, a movable arm is placed in the third and sixth box and then the sand may be run through all six, or the plant may be operated in two rows of three boxes each. The water should be as clean as possible and the pressure at the eductor should be under a head of 30 to 40 feet, depending upon the nature of the material to be washed.

Water-Jet Ash Conveyor.

This apparatus is used in stationary plants and on board of boats for conveying ashes and cinders from the boiler room. The working of these ash ejectors involves the same principle as in the water-jet eductors previously described, *i. e.*, a jet of high pressure water discharging from a nozzle throws the ashes and cinders, which are

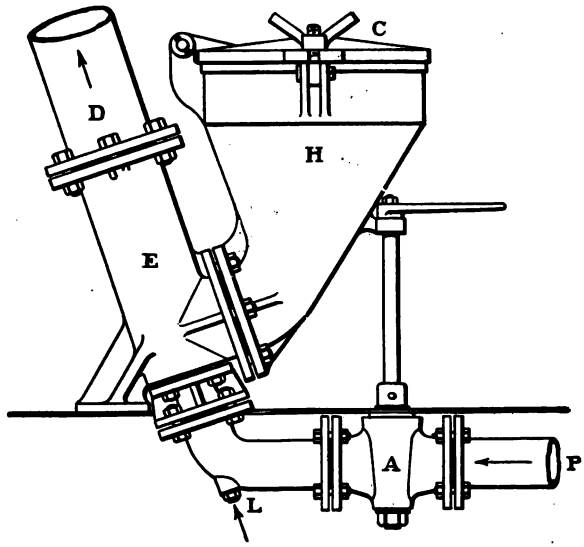


Fig. 113. Water-Jet Ash Conveyor.

carried to the jet by means of a hopper, to the place of destination. Fig. 113 shows the jet apparatus with hopper and cock complete. The jet apparatus proper *E* is made of steel to resist the grinding action of the material. The piping is also made of steel and the elbows, which are exposed to considerable wear, are plated with chilled steel plates and can be easily replaced. These conveyors are simple, practically dustless, reliable, of low first cost. The repairs are slight.

In Fig. 113 *A* is a cock, *C* the cover, *D* the discharge, *E* the conveyor, *H* the hopper, *L* the air valve, *P* the water-pressure pipe. The latter must have a diameter of 3 inches, and the water pressure should be at least 150 pounds. In order to start the conveyor, the water-pressure pump is started, then the cover *C* is raised from the hopper *H* and ashes and clinkers are put in as uniformly as possible;

the cinders must be crushed in order to pass through the grates in the hopper. The air valve *L* admits air only while the conveyor is discharging into *D* and is automatically closed, when the discharge is stopped. In order to stop the plant, the cover *C* of the hopper is closed; the water pressure is shut off by means of cock *A*.

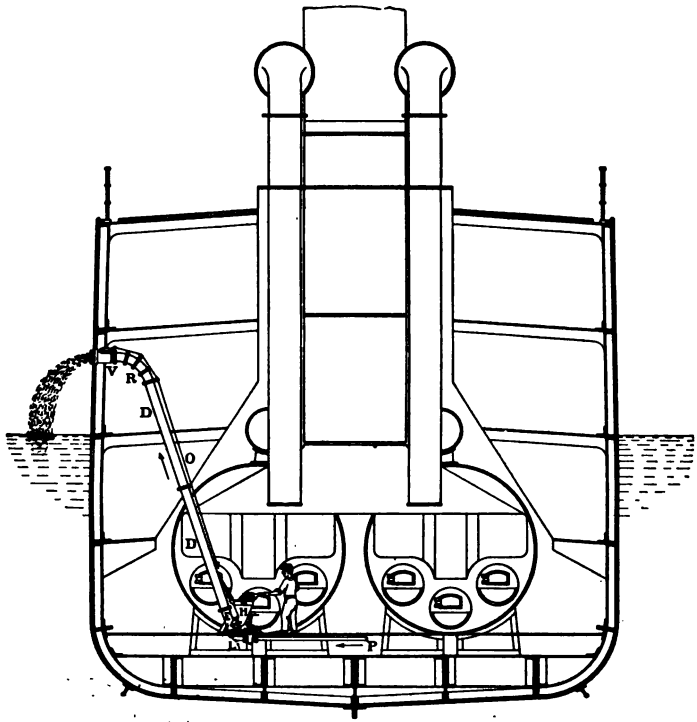


FIG. 114. ASH CONVEYOR ON STEAMSHIP.

Fig. 114 shows a plant on board of a boat. *D* is the discharge pipe, *E* the conveyor, *H* the hopper, *O* a rod to operate the check valve, *P* the pressure pipe and *V* the check valve. Fig. 115 shows a stationary plant. *C* is the cock, *D* the discharge pipe, *H* the hopper and *P* the pressure pipe.

STEAM-JET CONVEYORS FOR DUST AND POWDER.

In the preceding chapter we have described the water-jet machines for handling ashes and coarse material; we will now describe the jet apparatus for moving dust and powdered materials. This conveyor is shown in Fig. 116 and is constructed with an annular steam

opening. The jet creates a vacuum and draws in the material generally by means of a mouthpiece as shown in Fig. 117. The material is conveyed to an outside place, or to a tank filled with water

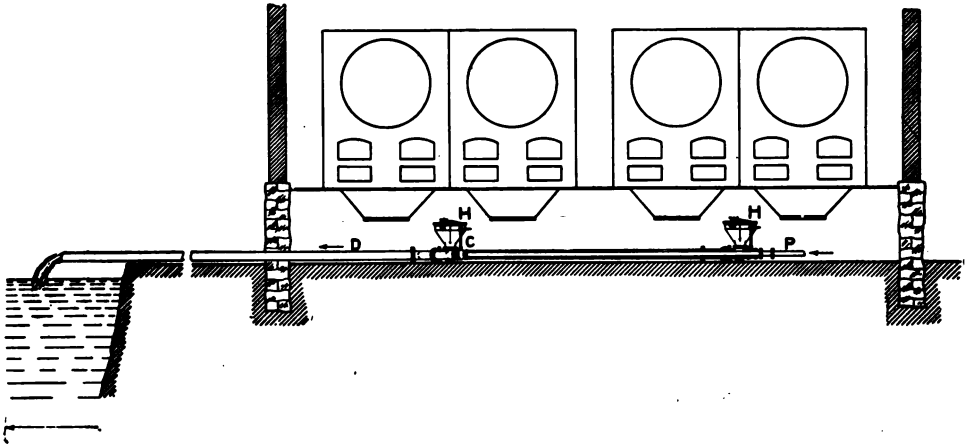


FIG. 115. ASH CONVEYOR IN STATIONARY PLANT.

to precipitate the obnoxious dust. Precipitation can also be accomplished by water sprayed into the discharge pipe, as shown in Fig.

FIG. 116. DUST CONVEYOR.

117. In this illustration C is the dust conveyor, H a hose, M the mouthpiece and T the water inlet for assisting the flow.

This apparatus is well suited for the cleaning of railroad cars. Steam is always at disposal in the yards either from stationary

plants or from locomotives and it is easy to provide at a suitable place either a removable outfit, or a stationary plant as shown in Fig. 118. Steam connection is made by means of a hose. In Fig.

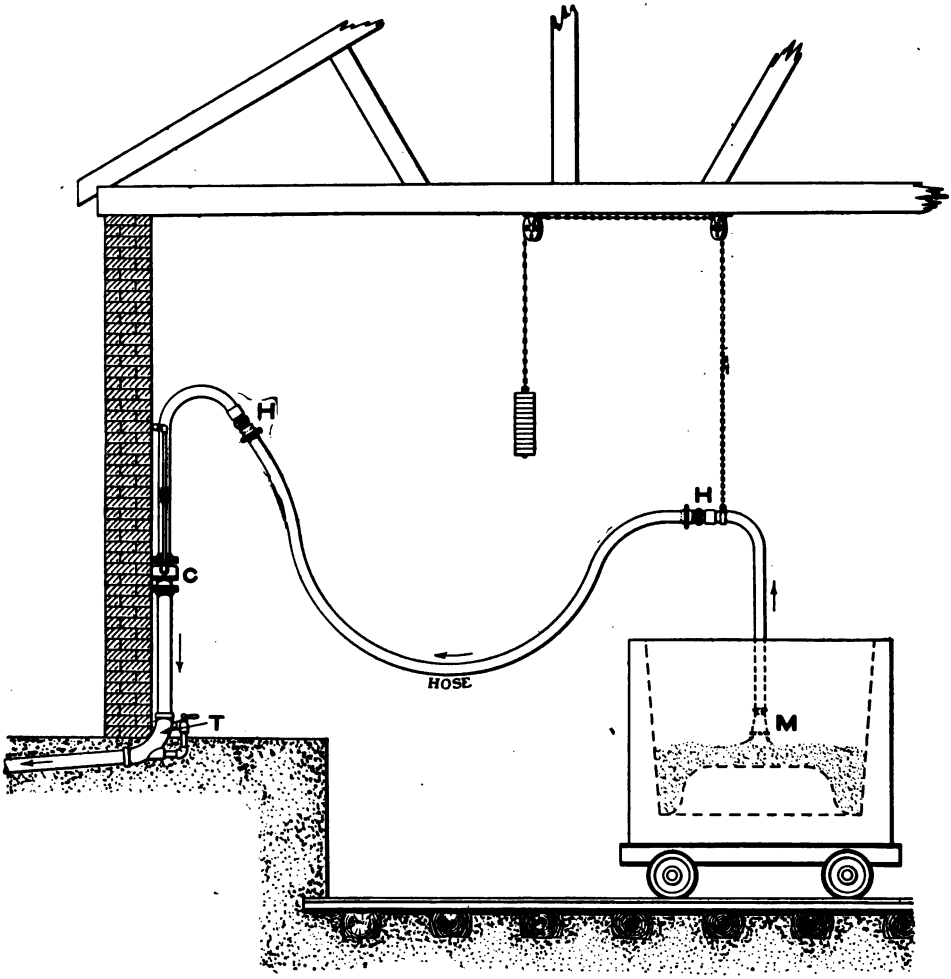


FIG. 117. INSTALLATION OF STEAM-JET DUST CONVEYOR.

118 *C* are the railroad cars, *E* is the steam-jet conveyor outfit, *L* the locomotive, *M* the mouthpiece and *S* are stationary posts to connect the vacuum hose. This arrangment takes very little space, the plant is reliable and the operation simple.

Where steam is at disposal a similar apparatus is used for removing dust from carpets, etc., in hotels, offices, private houses, etc.

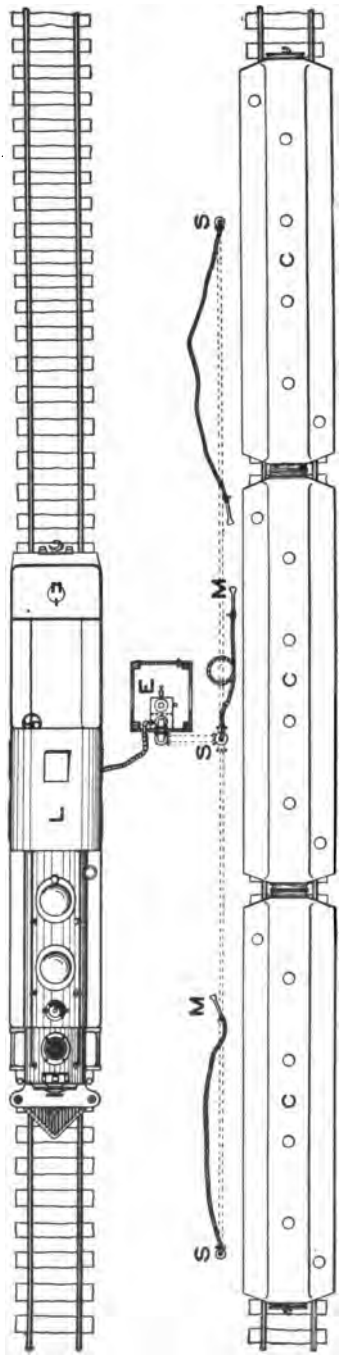


FIG. 118. CONVEYOR USED BY RAILROAD COMPANY.

The arrangement is shown in Fig. 119. *C* is the conveyor, *N* the spray nozzles, *S* the steam pipe, *W* the water pipe, *H* are the hose couplings, *D* is the sewer pipe and *V* the vacuum line. (Such installations can also be made with water-jet machines working with

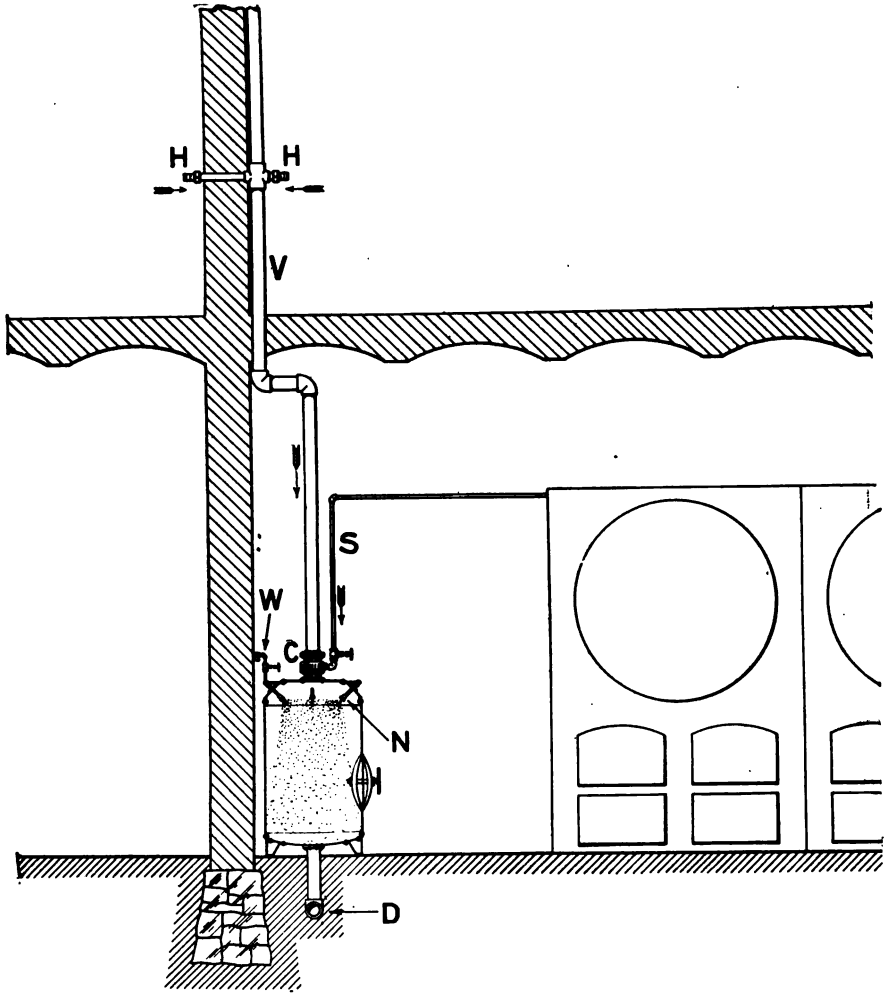


FIG. 119. VACUUM CLEANER.

water pressure.) In office and hotel buildings the apparatus is usually installed in the basement, and the vacuum pipe is extended through the building. At the different floors hose pipe branches are connected with mouthpieces.

Steam-jet conveyors are also used for handling pulverized paints and chemicals. By using this arrangement for the filling of barrels this operation becomes a dustless performance. The material settles in the barrel on account of its low velocity and a small percentage of the material only passes through the pipe line to the exhauster. Here it is caught and collected in a filter installed in front of the exhauster. Fig. 120 shows such an installation: *A* is the air admis-

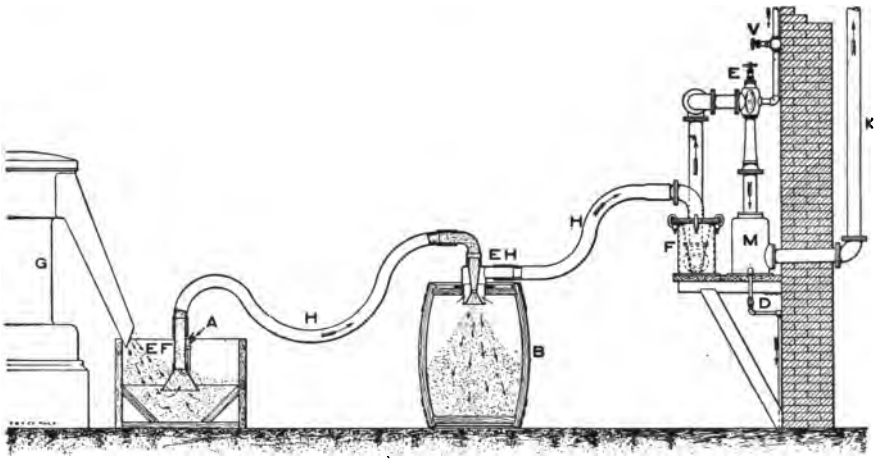


FIG. 120. HANDLING CHEMICALS.

sion, *B* the barrel, *D* the discharge of condensed water, *E* the exhauster, *EF* the suction foot, *EH* the discharge head, *F* the filter, *G* a pulverizer, *H* the suction hose, *K* the discharge from the exhauster, *M* the muffler and *V* the steam valve.

Table XXII. gives the dimensions and capacities of these conveyors.

TABLE XXII.

Size. Inches	Size of Pipes in Inches.			Approx. Lbs of Discharge per Min.
	Conduit, *A*.	Steam, *B*.	Air, *C*.	
3	3	¾	1	35
4	4	1	1½	60
6	6	1½	2	130
8	8	2	2½	230

FOURTH PART.

ATOMIZING LIQUIDS.

Centrifugal Spray Nozzles.

Spray nozzles are made for various purposes, according to the pressure of the liquid to be atomized. The effect obtained depends upon the diameter and shape of the orifice. Fig. 121 shows the general construction of a nozzle, Fig. 122 illustrates an atomizing nozzle, which throws a wide angle spray and Fig. 123 the standard and cooling nozzle, which throws a smaller angle spray. Table XXIII. gives the capacities. In connection with this table it should be noted that the standard nozzles are used for all purposes except atomizing and can be operated with pressures from 15 to 20 pounds. The table gives the capacity at 18 pounds pressure. With 15 pounds pressure the capacity is 15 per cent. less, with 20 pounds 5 per cent. more. The small atomizing nozzles should be run at pressures from 40 to 80 pounds. The capacity shown at 40 pounds will be increased 40 per cent. at 80 pounds.

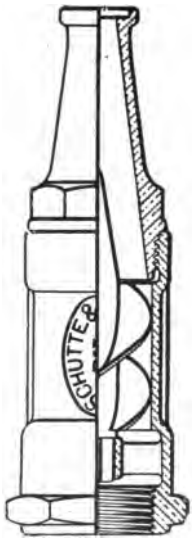


Fig. 121. Spray Nozzle.

The spray nozzles are used for cooling and absorbing gases, ventilating, collecting dust, atomizing liquids and re-cooling water.

Fig. 124 shows the application of the nozzle for precipitating coal dust floating in the dry atmosphere of coal mines, whereby the danger of explosion is removed at the lowest possible expense with the least quantity of water.

Fig. 125 illustrates a nozzle attachment for carding machines of spinning mills, where the material has to be treated with a certain oil mixture. Three spray nozzles are provided, one on either side, and one in the center, the latter being located somewhat higher. Either the two lower sprays or the upper one is used. Regulation

FIG. 122. ATOMIZING NOZZLE.

of the capacity is effected by changing the pressure. The pressure pipe to the nozzles is so arranged that part of the liquid returns to the tank, as the oil mixture must be kept in constant circulation in order to remain uniform. The tank contains a steam-jet apparatus

FIG. 123. COOLING NOZZLE.

in order to keep the material liquid and at the proper temperature. A belt-driven pump is preferably used to draw the oil from the tank and to force it to the nozzles.

TABLE XXIII.

Size of Orifice *O* in mm.	Size Diameter of Pipe in Inches.	Standard Nozzles. Capacity in Gallons per Hour under 18 Lbs. Pressure.	Atomizing Nozzles. Capacity in Gallons per Hour under 40 Lbs. Pressure.
¾	⅛ *X*		6
1	⅛ *A*		10
1¼	⅛ *B*		15
1¾	⅛ *C*		30
2½	⅛ *D*	60	60
3½	¼	120	120
4½	⅜	200	200
6	½	360	360
7½	¾	560	560
10	1	1,000	
12½	1¼	1,560	
15	1½	2,250	
20	2	4,000	
25	2½	6,250	Note that the small nozzles, *A*, *B*, *C*, *D* and *X* differ in capacity only. All are threaded for attachment to one eighth inch pipe.
30	3	9,000	
40	4	16,000	
50	5	25,000	
60	6	36,000	
70	7	49,000	
80	8	64,000	
90	9	81,000	
100	10	100,000	

FIG. 124. PRECIPITATING COAL DUST.

Fig. 126 shows the application of a small atomizing nozzle for eliminating the suds, which collects on the plates of paper machines and often prevents the uniform distribution of the material on the wire cloths. The pressure pipe is installed across the plate of the paper machines and a sufficient number of nozzles is provided to

cover the entire width of the paper with water. As these nozzles atomize only 4 gallons per hour at 60 pounds pressure, the diluting

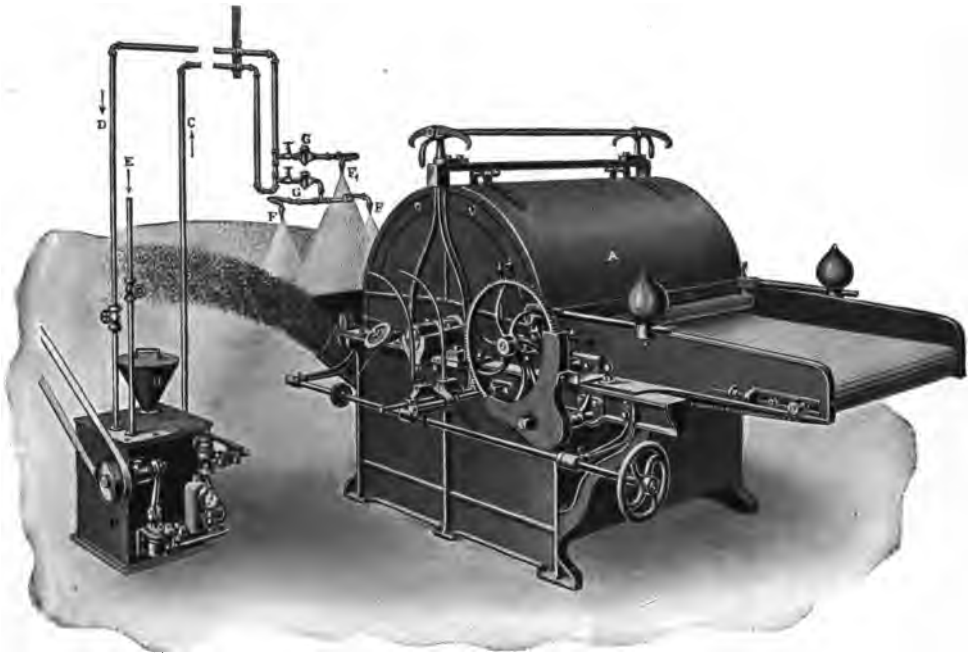


FIG. 125. NOZZLE ON CARDING MACHINE.

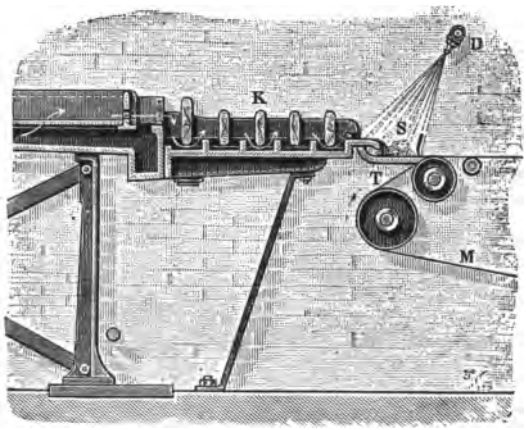


FIG. 126. NOZZLE ON PAPER MACHINE.

effect need not be taken into consideration. The minimum water pressure to be used is 45 pounds.

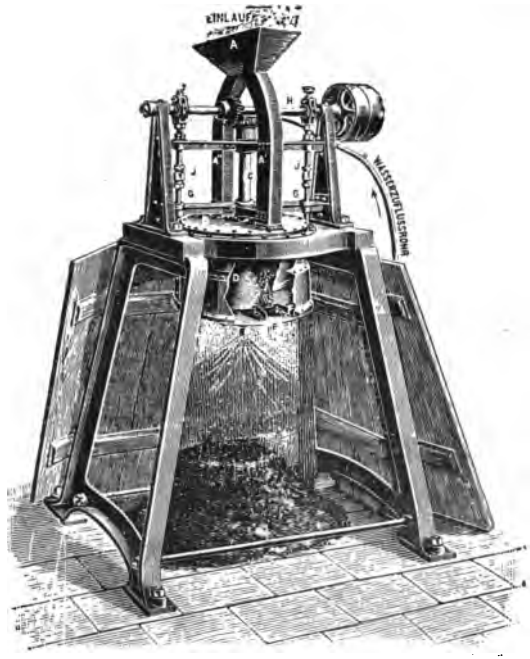


FIG. 127. NOZZLE IN CEMENT MILL.

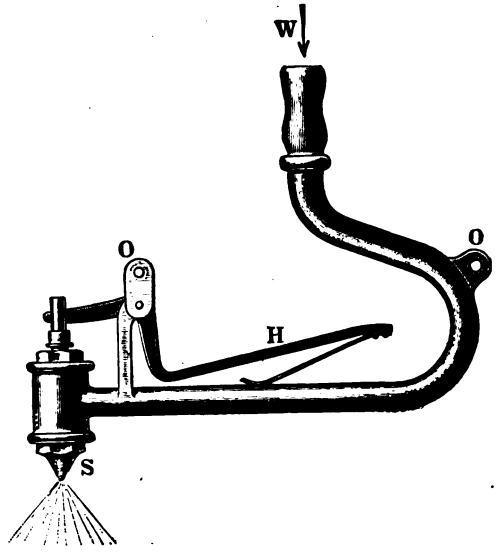


FIG. 128. SPRAY NOZZLES FOR MOISTENING TOBACCO.

FIG. 129. MOISTENING TOBACCO LEAVES.

Fig. 127 shows an installation for reducing the dust and for sprinkling the goods in the fire-clay and cement industries. The sprinkling of the goods is most conveniently effected while the material is in motion. The cut shows the nozzles installed directly on the grinding machines. The material runs through the inlet *A* into the machine, then through the rotating cylinder *O* and the shaking grate *E*. From here it drops down and mixes with the water. The nozzles are installed underneath the grate and the pressure water is supplied through the vertical shaft of the machine.

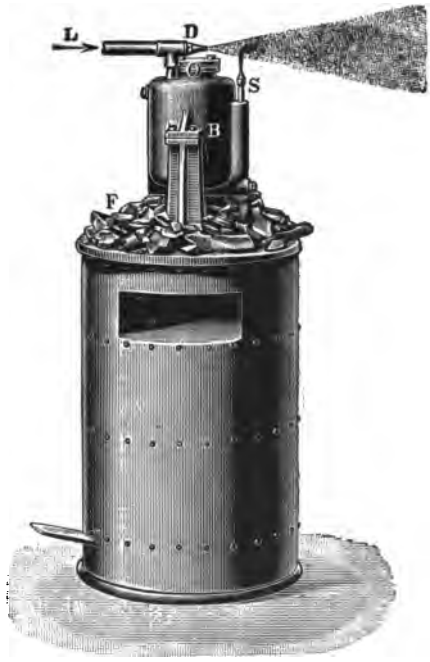


FIG. 130. ATOMIZING LEAD.

The application of the nozzle for moistening tobacco leaves produces an absolutely uniform humidity. A nozzle built for this purpose is shown in Fig. 128, its application in Fig. 129. In the

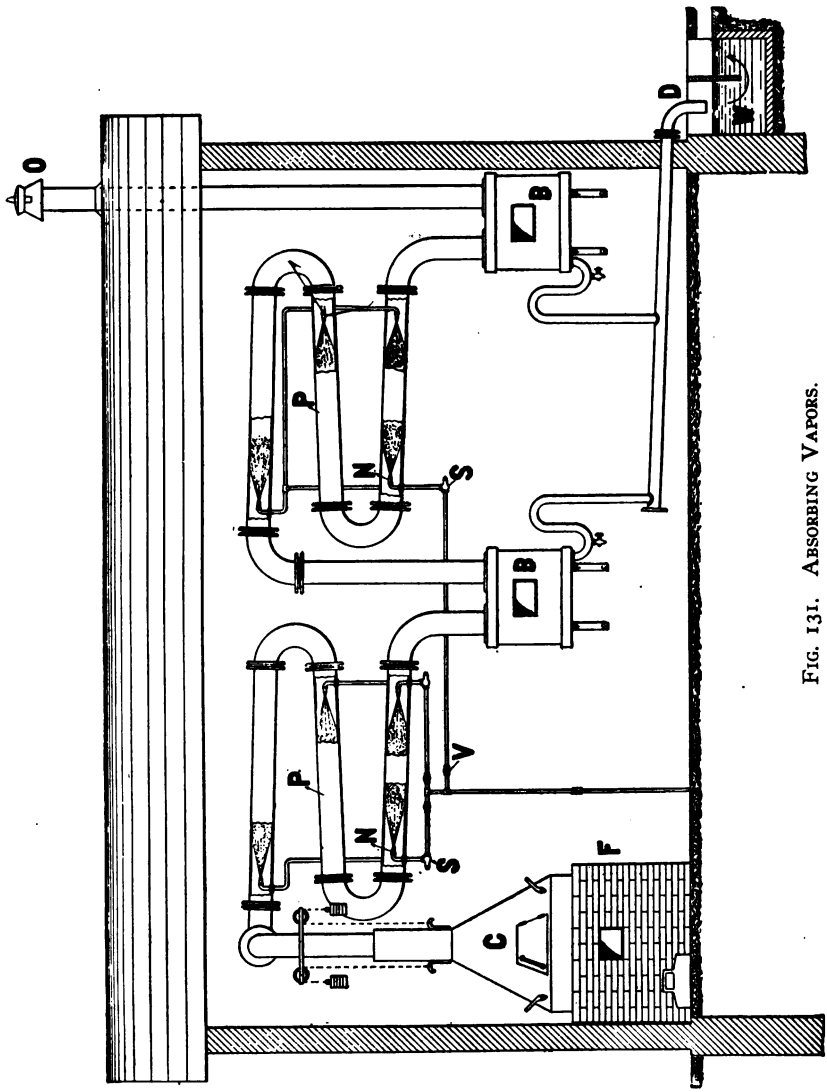


FIG. 131. ABSORBING VAPORS.

latter cut a hand pump is provided to produce a water pressure of at least 30 pounds, while in places where water of such pressure is at disposal the nozzle is simply connected to the water pipe.

An installation of a nozzle for atomizing liquid lead is illustrated in Fig. 130. The liquid lead is put in the cast-iron tank *B* and is kept liquid by means of a charcoal fire. After closing the charging hole the tank *B* is put under pressure by means of steam or air admitted through pipe *L*. The atomizing is effected partly by nozzle *S* and partly by nozzle *D*.

Spray Nozzles in the Chemical and Metallurgical Industries.

Obnoxious vapors of the paint and varnish industries are successfully removed by a water spray issuing from a nozzle. The in-

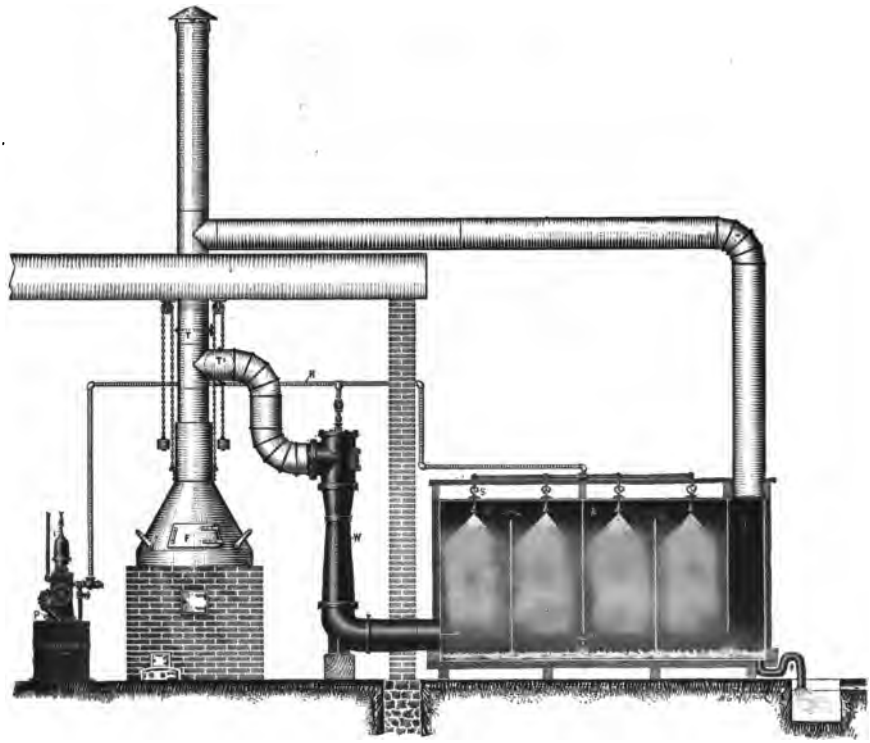


Fig. 132. Condensing Vapors.

stallation is simple, the quantity of water consumed very small, while at the same time, by the action of the nozzle, the draft necessary to move the gases is created. This application is shown in Fig. 131. Hoods *C* which are connected to a pipe system *P* are placed on top of the furnaces *F*. The nozzles *N* are installed in the piping. A

draft is created in the direction of the spray and the vapors are condensed by being drawn into the spray. The cooling water and the condensed oil flow into oil separators *B*.

Another arrangement for condensing foul vapors is shown in Fig. 132. The vapors are drawn off by a water-jet exhauster and are pressed into the absorption chamber, where the nozzles are provided.

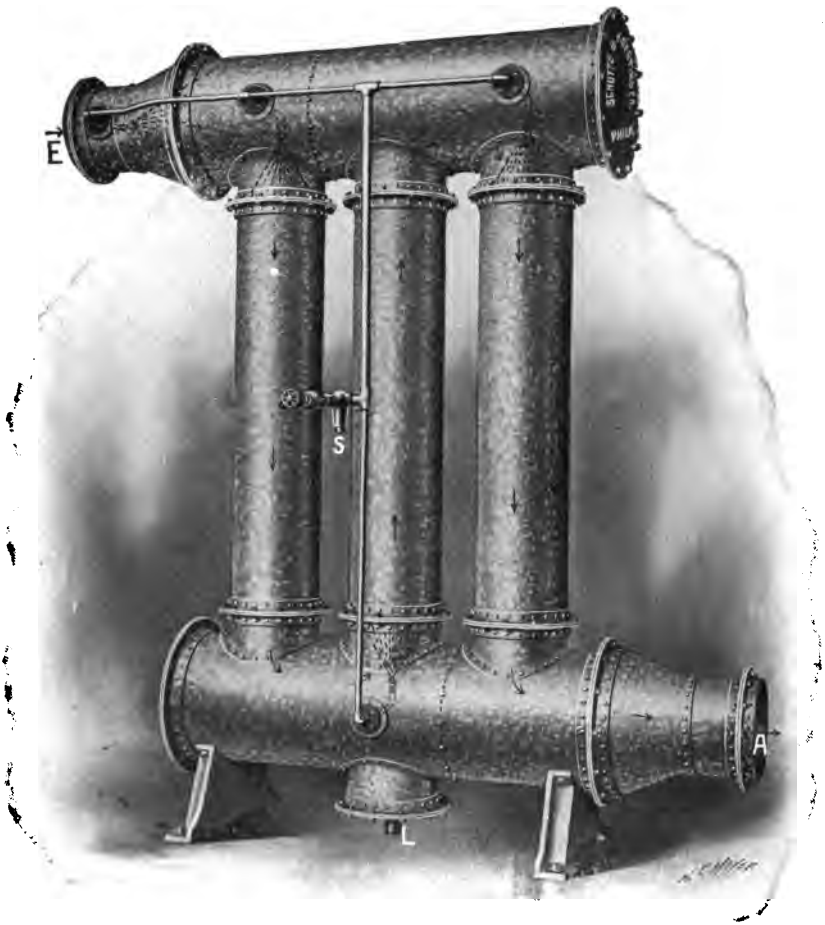


FIG. 133. DUST COLLECTOR.

The chamber is equipped with partitions in order to increase the length of the travel of the vapors.

Dust collecting by means of nozzles is successfully applied in stoneware and cement mills, paint factories, paper mills, breweries,

etc. Fig. 133 shows such an apparatus. The air or gases enter at *E* and are discharged in a clean state at *A*. The air is forced through the dust collector by jet ventilators or rotary fans. The dotted lines show the arrangement of the nozzles. The water passes

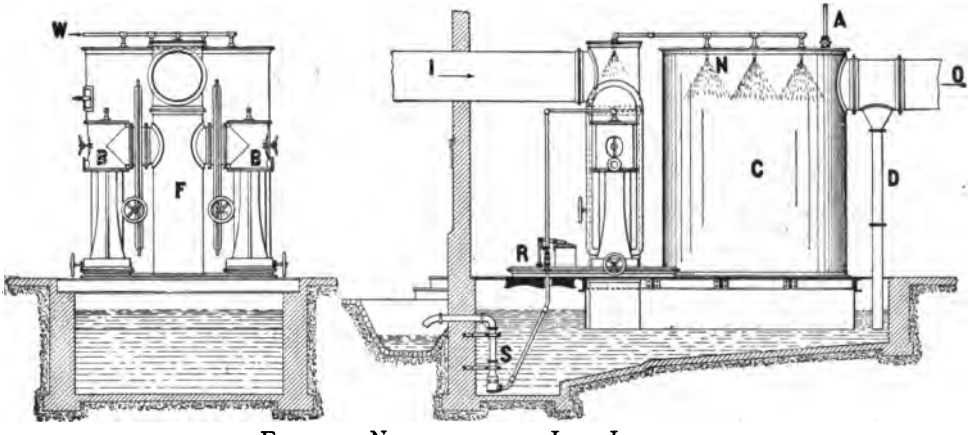


FIG. 134. NOZZLES IN THE IRON INDUSTRY.

through strainer *S* to the nozzles and is discharged through *L*. Fig. 134 illustrates the application of spray nozzles in the purification of blast furnace gas.

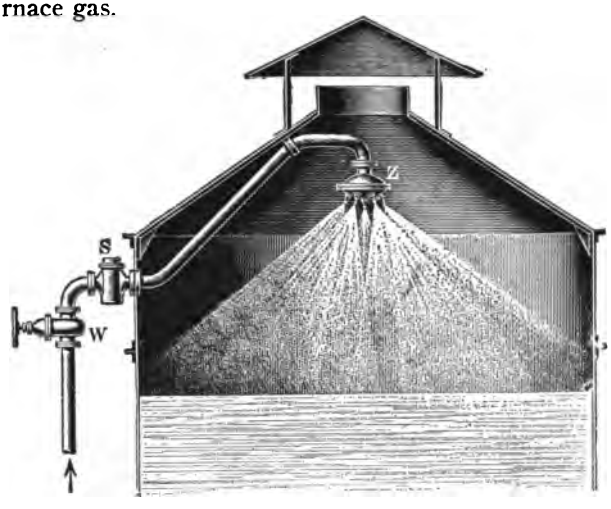


FIG. 135. NOZZLES CLEANSING OIL.

Perfect cleansing of crude oil at the smallest possible consumption of water is effected by the proper use of these nozzles. This application is shown in Fig. 135.

By conveying atomized water to the sulphuric acid chambers, the efficiency of the latter is highly increased, as compared to the old

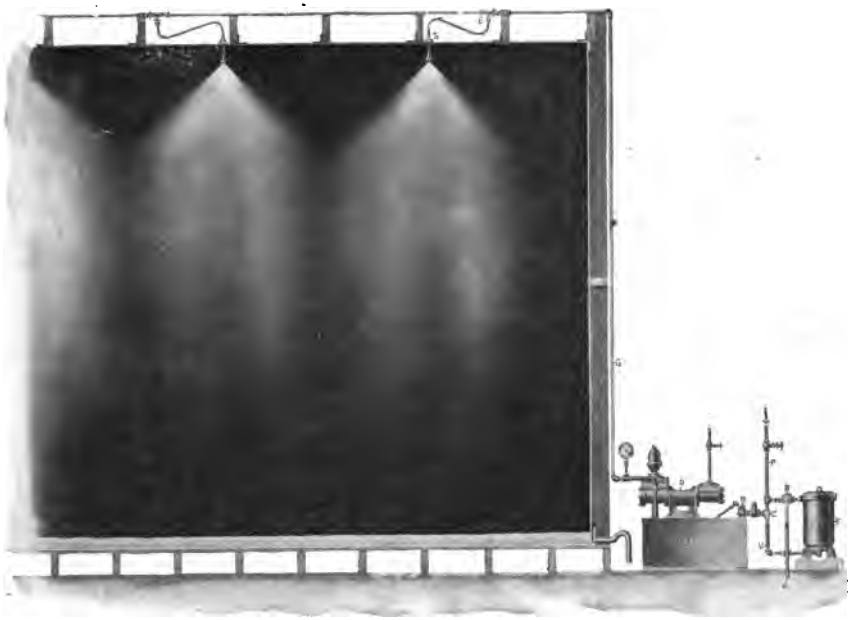


FIG. 136. NOZZLES IN SULPHURIC ACID PLANT.

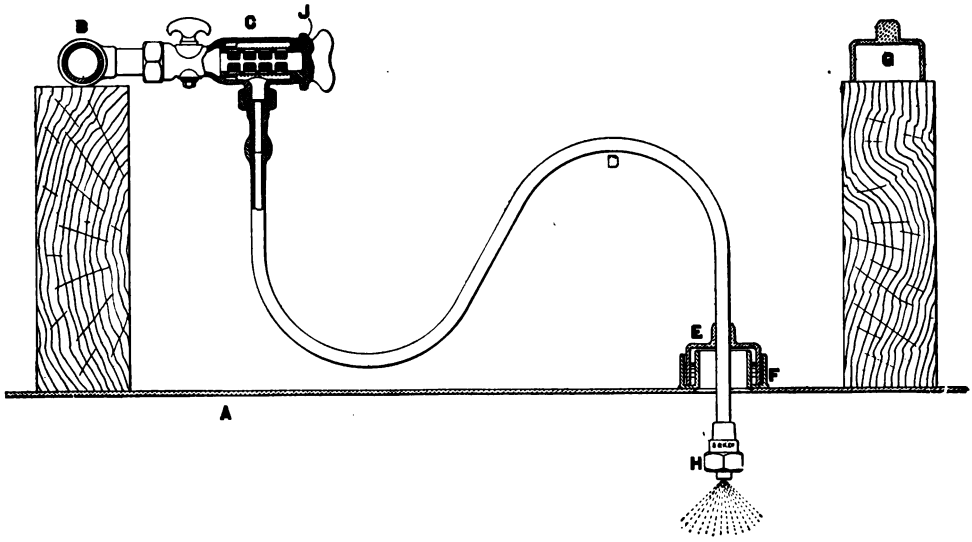


FIG. 137. GLASS OR PLATINUM NOZZLES.

method of injecting steam into the chambers. Fig. 136 shows the arrangement of glass or platinum spray nozzles in a sulphuric acid plant. The water enters at *P*, passes through the filter *F* and then through the float valve *B* into the tank; from here it is taken by the pump and forced at 60 pounds pressure to the nozzles installed on the top of the chambers. Each nozzle is protected by a strainer. *S* are the nozzles, *E* a combination cock and strainer, *C* a cock, *G* the pressure pipe to the nozzles, *O* the pressure pump, *R* a regulating cock for the filter and *W* an overflow pipe. The lead pipe between the nozzle and the combined cock and strainer is made long enough to conveniently swing the nozzle out for inspection, as shown in Fig. 137. The nozzles are also made of hard rubber, with screw or hose connection for applications where other material cannot be used. Hard-rubber nozzles are illustrated in Figs. 138, 139 and 140.

FIG. 138. HARD-RUBBER NOZZLE.

An installation of hard-rubber nozzles for the absorption of hydrofluoric acid gas in the manufacture of superphosphate is shown in

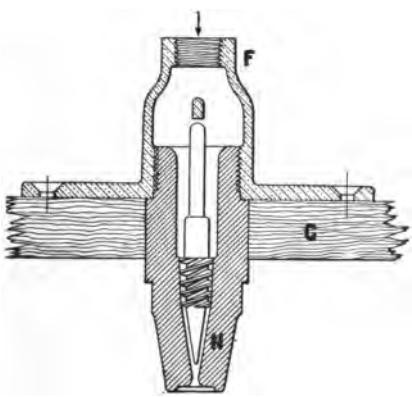


FIG. 139. HARD-RUBBER NOZZLE.

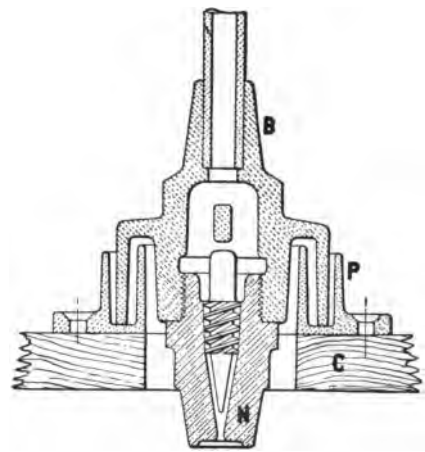


FIG. 140. HARD-RUBBER NOZZLE.

Fig. 141. A hood, placed over the pit, is connected to a wooden tower. At the top of the latter rubber nozzles are provided. A

suitable size for these towers is 6 feet square and a height of 30 feet. The vapors, freed of hydrofluoric gas, pass through the outlet to a chimney or fan. Two styles of hard-rubber nozzles are built for this purpose. The one shown in Fig. 139 is arranged for

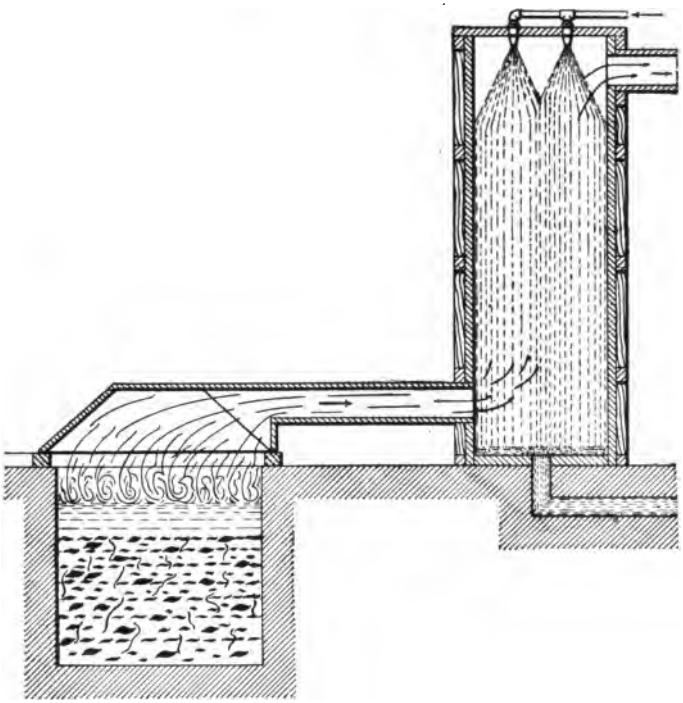


FIG. 141. ABSORBING HYDROFLUORIC GAS.

rigidly fastening the nozzle to the chamber, while the one shown in Fig. 140 is equipped with a water seal, which permits the nozzle to be swung out for inspection.

The nozzles can also be arranged at the bottom of towers, as shown in Fig. 142. Fig. 143 illustrates the application of brass nozzles for the recovery of valuable dust in metal refineries.

SPRAY COOLING.

One of the most important uses of the spray nozzles is the re-cooling of condensing water, where the water supply available for the condenser is insufficient, as in such cases the whole or part of the limited supply has to be used over and over again, which necessitates the cooling of the hot water. The same principle is used in

all kinds of cooling plants, *i. e.*, the distribution of water in a spray of large area, the cooling being effected by the contact with air.

The spray nozzles are the simplest means to attain this result, as the first cost is low, as they require no repairs and as they operate with absolute certainty and at the smallest expenditure of power.

The water of about 15 pounds pressure issuing from the nozzle is torn into spray, is thrown through the air and creates its own continuous current. The disintegration of the water decreases the temperature, and this added to the effect of the air current reduces the temperature of the water to about the temperature of the surrounding air, under favorable atmospheric conditions even below that, but always to a temperature sufficiently low for effective condensation. The average reduction of temperature is 30 to 35° Fahr.

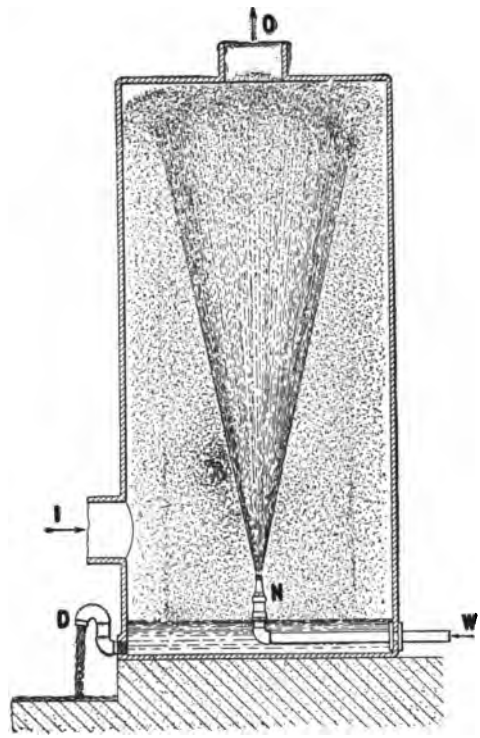


FIG. 142. SPRAY NOZZLE IN CLOSED CHAMBER.

The temperature of the water to be sprayed must not exceed 115°. At a higher temperature the vapors formed would represent a waste of water and would be objectionable.

If the condenser discharge is of higher temperature, some of the cooled water is returned to the hot well in order to reduce the temperature to 115° or below; in this case the quantity of water sprayed is larger than that discharged from the condenser. However, this additional quantity is always small and is required during the hot weather only. In winter time the amount sprayed can be less than that passed through the condenser.

To provide, however, for extreme demands, provision should be

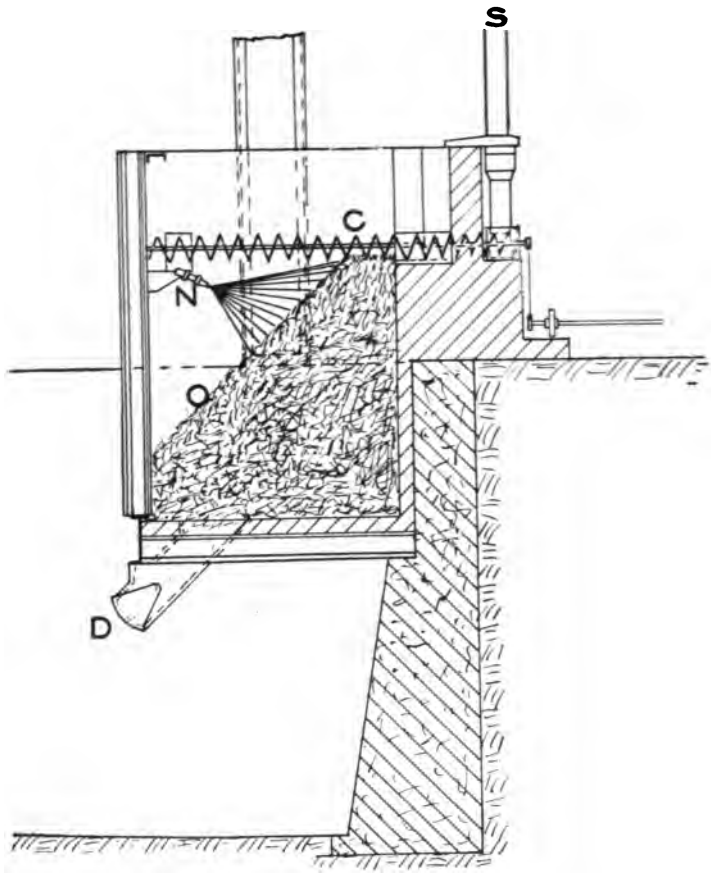


FIG. 143. NOZZLE IN METAL REFINERY.

made to have a pump of sufficient capacity and a sufficient number of nozzles, so that the required number of them can be turned on, while the pump is run at a speed corresponding to the number of nozzles in operation. The spraying capacity should be about 25 per cent. in excess of the maximum volume needed by the condenser.

The amount of boiler feed recovered in condensation is equal to and offsets the loss by the evaporation in spraying, so that no additional fresh water (beyond that required for boiler feed) need be provided for in a re-cooling condenser plant.

Where a fair amount of space is at disposal, this is the best system to use. The area required for a spray-cooling plant is about one square foot per three cubic feet of water cooled per hour, or four

square feet per horse-power per hour. For an ordinary cooling pond without spray nozzles 30 square feet per three cubic feet of water cooled are required.

The cooling plant is preferably arranged over ponds, canals or natural water sources. The nozzles can be arranged in straight

FIG. 144. SPRAY COOLING PLANT IN PHILADELPHIA.

lines or circles, preferably discharging at an angle of 30 degrees, and spaced as per table below. The cooling pond need only be shallow.

In places where strong winds carry the spray beyond the limits of the building or beyond the reservoir arranged on the roof of the

plant, it is necessary to surround the reservoir with a fence of inclined slats, in order to arrest the spray.

Calculating an evaporation of 30 pounds of water per horse-power in the engine, the spraying capacity required would be one and one half gallons per horse-power per minute.

The power expenditure for spraying in pumping one and one half gallons per horse-power per minute against a pressure of 15

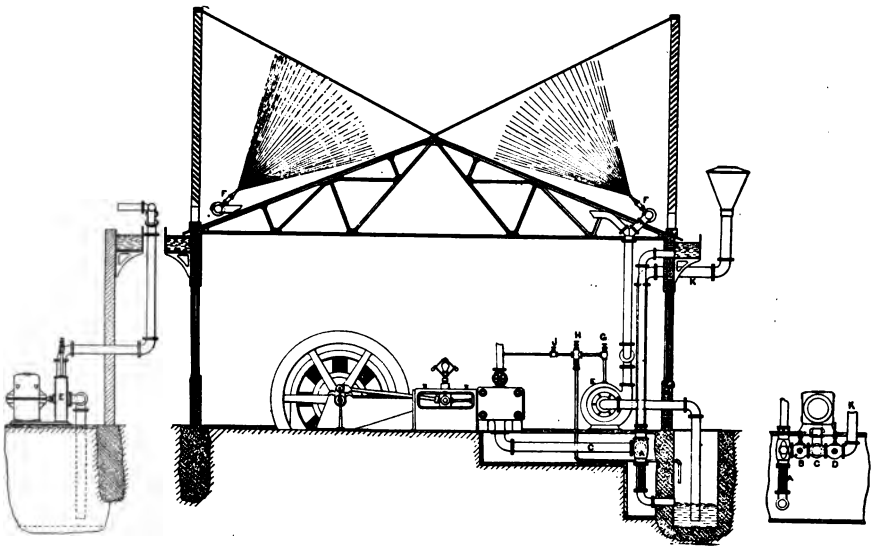


FIG. 145. SPRAY COOLING PLANT ON ROOF.

pounds, requires theoretically one ninetieth of one horse-power, which means an expenditure of less than 2 per cent. at a practical efficiency of 60 per cent.

Table XXIV. gives the capacities.

TABLE XXIV.

No.	Size of Pipes in Inches.	Capacity. Gallons per Minute.	No. of Eng. H.P. each Nozzle Takes Care of.	Distance Nozzles are Spaced Apart in Feet.	Distance Between Rows.
10	1	15	10	8	20 ft.
15	1½	37.5	25	10	30
30	3	150	100	15	40

Fig. 144 shows a spray nozzle plant installed at the Second and Wyoming Power House of the Philadelphia Rapid Transit Company. In Fig. 145, which illustrates a plant on the roof of an

engine house, *A* is the condenser, *B* the horizontal check valve, *D* the free exhaust valve, *E* the centrifugal pump and *F* the spray nozzles. Fig. 146 shows the spray cooling at the electric plant at Deadwood, S. D.

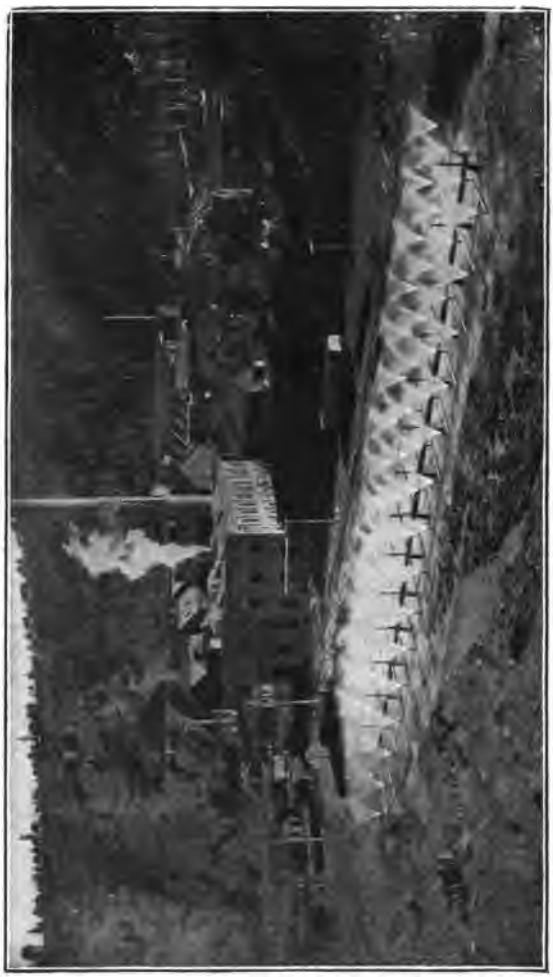


FIG. 146. SPRAY COOLING PLANT IN DEADWOOD.

MOIST VENTILATORS.

This instrument, of which a type is shown in Fig. 147, is used for moistening air, for ventilating, for precipitating dust and for absorbing obnoxious gases. The motive power is a fine water spray, produced by pressure water which is being forced through spray nozzles. The air drawn in by the water spray is moistened by being

TABLE XXV.

Size Diameter Discharge.	Cubic Feet Air Discharge per Hour as Water Pressure of 40 Lbs.	Diameter Water Supply Pipe.
2 inch.	1,000	⅛ inch.
3	2,000	¼
4	3,500	¼
6	6,000	½
8	12,000	¾
10	20,000	1

mixed with the water and is then forecd into the discharge pipe. By this method the air is uniformly moistened. The apparatus is

FIG. 147. MOIST VENTILATOR.

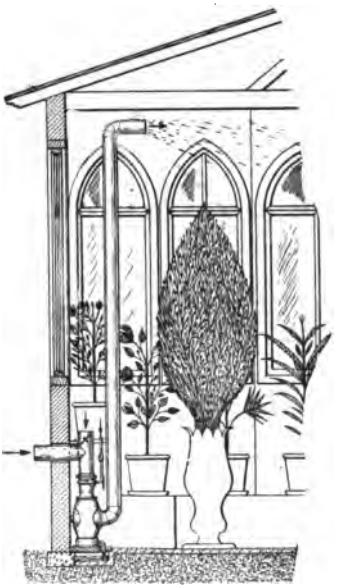


FIG. 148. VENTILATOR IN HOT HOUSE.

exceedingly simple, does not come out of order, and is not subject to wear and tear. The capacities are given in Table XXV.

A moist ventilator installed in a hothouse for producing a uniform humidity of the atmosphere is shown in Fig. 148. In such applications a hygrometer is always provided in the room and the work of the apparatus is regulated accordingly.

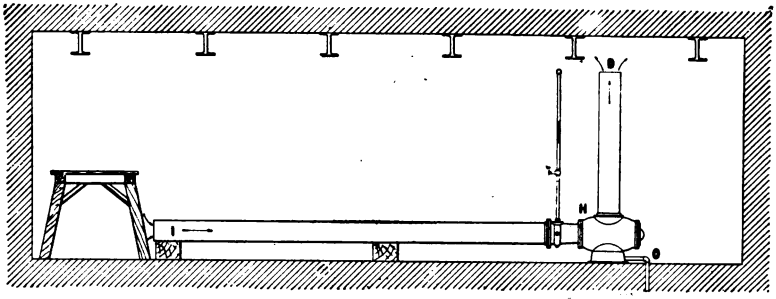


FIG. 149. VENTILATOR IN FERMENTING ROOM.

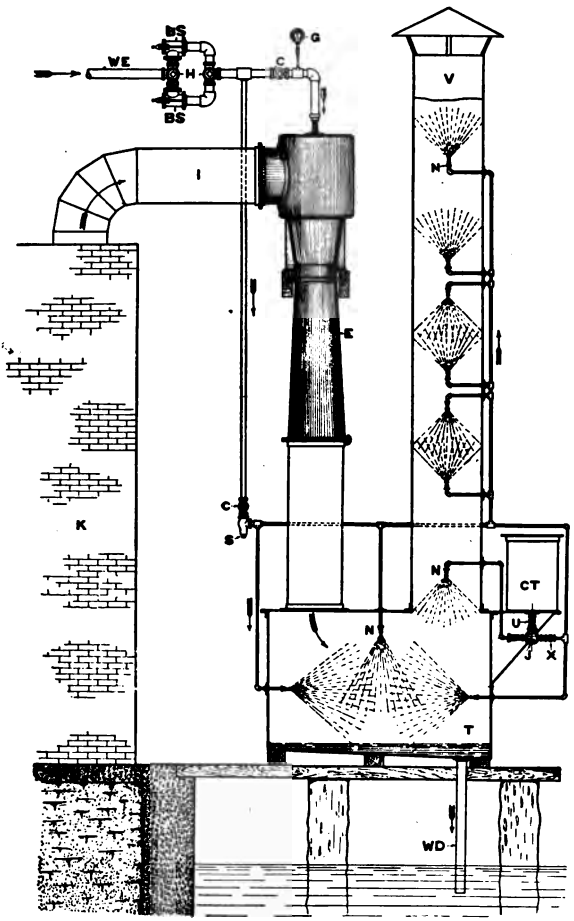


FIG. 150. VAPOR CONDENSER.

In fermenting rooms and certain kinds of store rooms it is imperative that the temperature should not rise above a certain maximum, and that, besides, a certain humidity should prevail. For such applications the apparatus is made with a cooling device installed in the air-suction pipe, the quantity of air to be drawn through the apparatus being exactly regulable. Fig. 149 illustrates

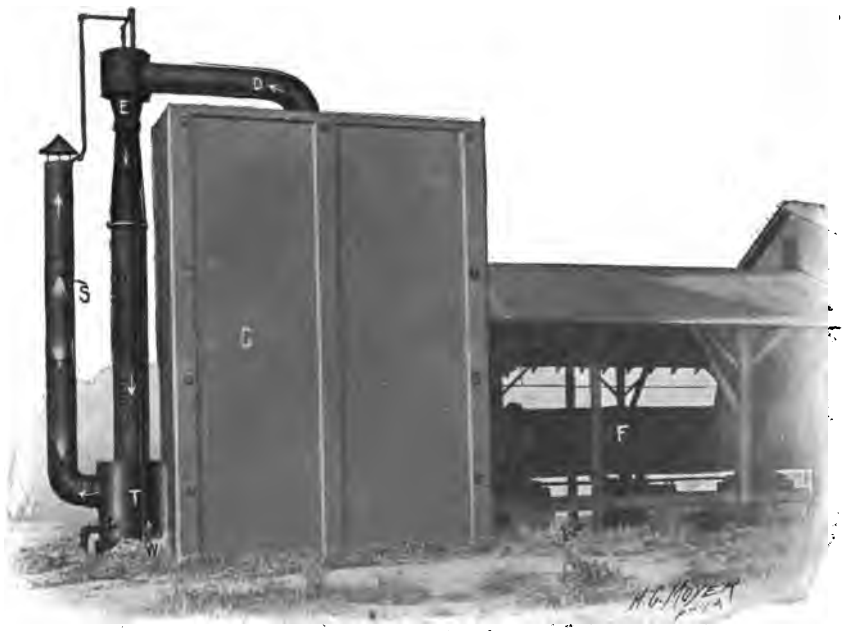


FIG. 151. VAPOR CONDENSER.

a moist ventilator installed horizontally in a store room or fermenting room. Other applications of these ventilators are: Removing dust in cutleries and glass works; humidifying the cheese cellars of dairies and the store rooms of dextrine and paper factories.

OBNOXIOUS VAPOR CONDENSER.

Some applications of this instrument have been already mentioned in the discussion of "Chemical Industries." The vapor condenser combines the work of a blower or fan with the work of a condenser and absorber, in so far as the driving power of a water spray is used to create the necessary draft, the gases being, at the same time, forced to pass through the water spray. After they have passed

the water-spray cone of the driving nozzle they enter the tail of the machine where they receive a centrifugal motion, whereby the

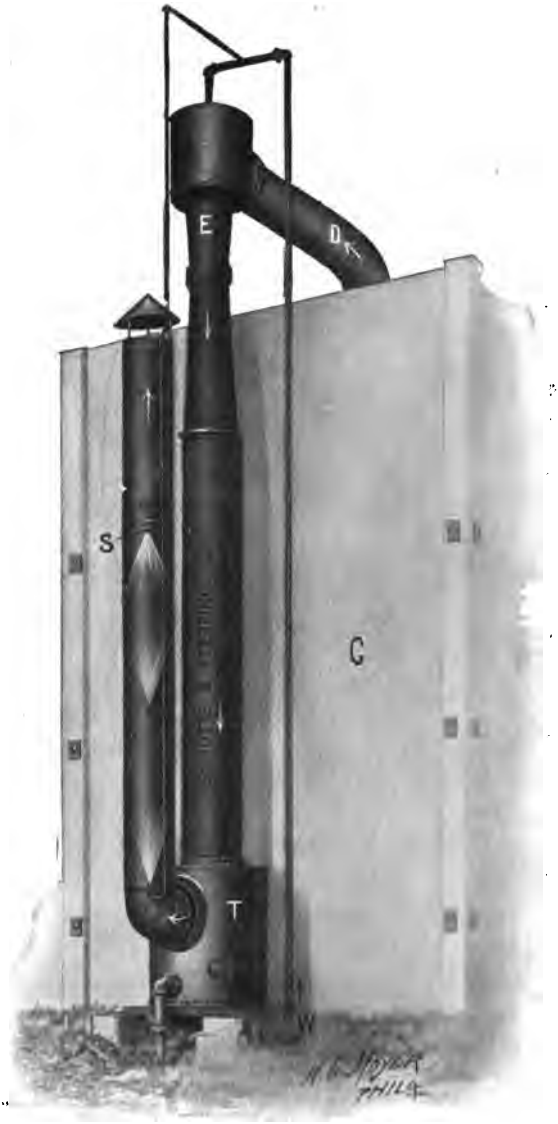


FIG. 152. VAPOR CONDENSER.

greatest part of the moisture, which was used to partly clean the gases, is separated. They are then discharged into a tank and a

conduit with spray nozzles, where they receive a further treatment for final absorption and purification.

Solutions of certain chemicals are used in places where the effect of water is insufficient. This is done, as shown in Fig. 150, by means of a water-jet apparatus, which draws the chemical or disinfectant from a tank, and injects it into the uptake, thus covering the gases passing through and reacting on them for the prevention of obnoxious vapors.

The vapor condensers are successfully used in the packing industries, in rendering establishments, fertilizer works, cotton oil

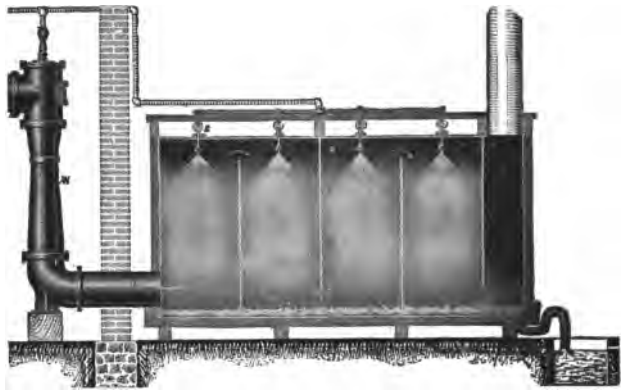


FIG. 153. VAPOR CONDENSER.

factories, slaughter houses, etc. Installations are shown in Figs. 151, 152 and 153.

SPRAY NOZZLES FOR OIL FIRING.

In this system of oil firing, which is shown in Fig. 154, the oil flows from a supply tank to a central pumping outfit, where it passes through a primary heater and flows through filters to a pressure pump. The latter delivers it at a pressure of 30 to 75 pounds (according to the evaporation required) through a second heater to the nozzles, which are installed in front of the boilers. In the second heater the oil is heated to 220 to 260° Fahr., *i. e.*, above the flash point at atmospheric pressure. The evaporation of the oil in the first stage is prevented by the pressure of the pumps. However, the moment the oil leaves the nozzles, the pressure is removed and the oil is atomized. This "thermic" atomization is

assisted by the mechanical action of the nozzles, and results in a perfectly intimate mixture of the oil with air, whereby a smokeless combustion is effected.

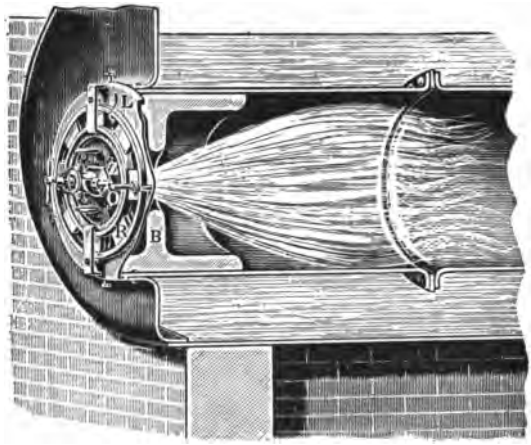


FIG. 154. OIL BURNER.

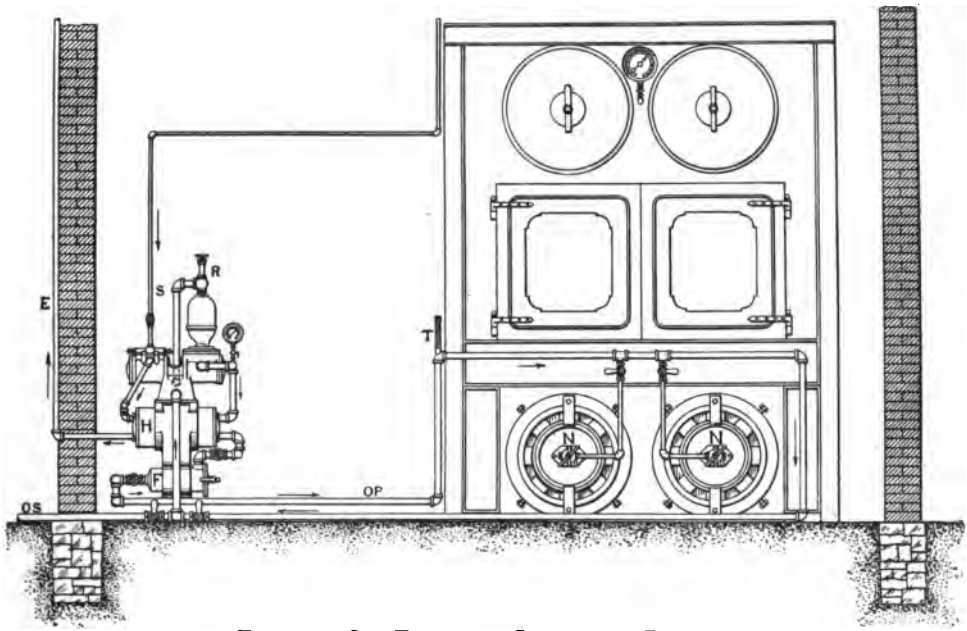


FIG. 155. OIL FIRING ON STATIONARY BOILERS.

As compared to the steam-jet system of burning oil, which will be described later, this system has the advantage of greater heat

economy, as in the jet system the steam has to be raised to the furnace temperature and, being lost for spraying, is lost to the boiler. This is especially disadvantageous in marine boilers, where the loss of water, frequently amounting to 100 per cent. of the weight of the oil, has to be replaced.

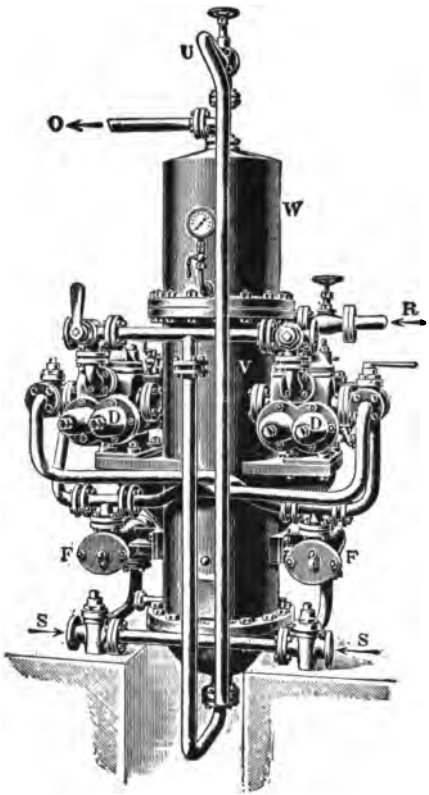


FIG. 156. PUMPING OUTFIT.

The centrifugal spray nozzle system is also superior to the various compressed air systems, as the power consumption of the former is much lower. Only 0.8 pound of steam are required to move 100 pounds of oil under a pressure of 75 pounds. For two heaters about 8 pounds of steam are required per 100 pounds of oil.

The installation of this system on stationary boilers is shown in Fig. 155. *E* is the exhaust pipe, *F* the filter, *H* the heater, *N* the centrifugal spray nozzles, *OP* the oil-pressure pipe, *OS* the oil supply pipe, *R* a safety valve, *S* the steam pipe and *T* a thermometer.

The pumping outfit, as shown in Fig. 156, contains all the parts required for moving, heating, filtering and controlling the oil. There are always two pumps provided, one for reserve. The two filters connected to the apparatus are used alternately; the pressure pipe from the pumps is provided with two strainers. The steam used for pumping and heating is recovered as condensed steam and returned to the boilers. A steam pressure reducing valve maintains a constant pressure and minimizes the attendance. An overflow and safety valve prevents the oil pressure from rising and thereby obviates waste of fuel. An air vessel is provided to maintain a uniform velocity in the pressure-pipe line. Oil- and steam-pressure

gauges, thermometer and oil line complete the outfit. In the illustration *D* are the steam pumps, *F* the filters, *O* the oil-pressure line,

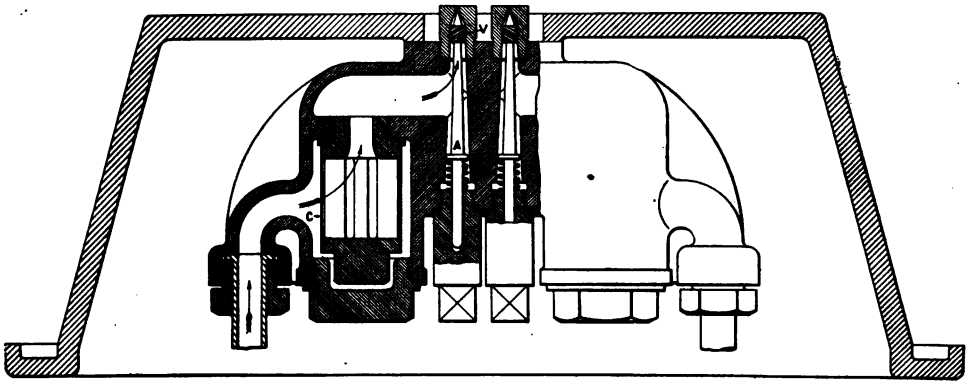


FIG. 157. SPRAY NOZZLES ON BOILER.

S the steam pipe, *U* the safety valve, *V* the heater and *W* the air vessel.

The spray nozzles are constructed for easy access and are thoroughly protected against clogging. The casing installed in front of the boilers contains one, two or four nozzles, according to the evaporation required. Each nozzle is protected by a strainer and

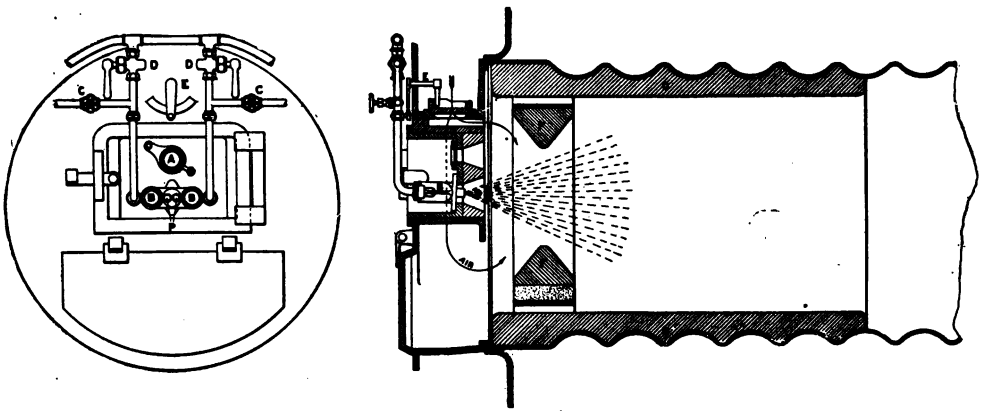


FIG. 158. AIR ADMISSION AND BRICK LINING.

each spiral may be removed and exchanged without disconnecting the casing from the boiler plate, so that interruptions from obstructions are avoided. A cock is provided on each nozzle, and a thermometer and pressure gauge is placed on each boiler in the old line.

Fig. 157 shows the spray nozzles on a boiler. *A* is a spiral, *B* the spring, *C* the filter and *V* the steel tips of the nozzles.

In order to properly admit the air to the liquid fuel, circular slide registers or cylindrical air admission slides are provided. The latter construction has the advantage of protecting the fireman from the radiant heat; but it takes a little more room than the circular register. Both registers regulate the amount of combustion air, the path of the air being determined by the brick lining.

Air admission and brick lining are shown in Fig. 158. *A* is a show glass, *B* the filters, *C* the steam pipe for blowing out the nozzle, *D* the oil cock, *E* the handle to operate the register, *P* the centrifugal spray nozzles, *F* and *G* the brick lining.

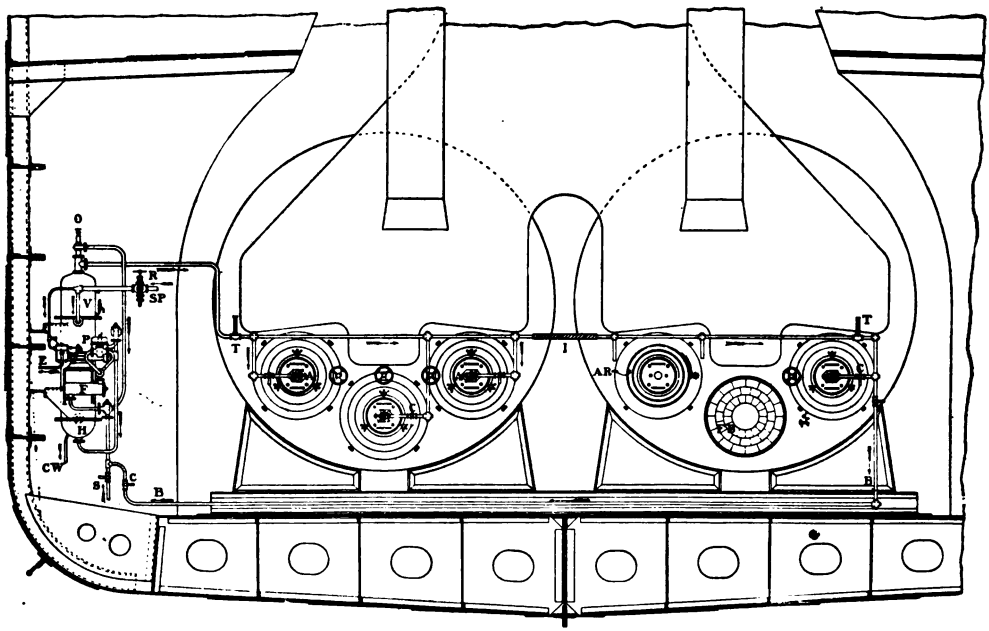


FIG. 159. OIL FIRING ON MARINE BOILERS.

Fig. 159 illustrates the oil firing on marine boilers. In this case the full section of the furnace is used, which means a gain in heating surface. The heating and the expansion is uniform. The short fire-clay lining in the furnace serves as a protection against the high temperature of the oil flame and allows a convenient restarting after short interruption, as the oil ignites on the incandescent fire-clay. In the illustration *A* is the centrifugal oil sprayer, *B* the circulating

line of heating, *C* a cock, *E* the exhaust of the pump, *F* the filter, *H* the oil heater, *O* the safety valve, *P* the steam pump, *R* the reducing valve, *S* the oil supply line, *T* the thermometer, *V* the air vessel, *AR* the air register, *CW* condensed water, *FB* fire brick and *SP* the steam-pressure line.

Oil firing on locomotives is shown in Fig. 160. *AV* is the air vessel, *CW* condensed water, *ES* exhaust steam line, *SV* safety

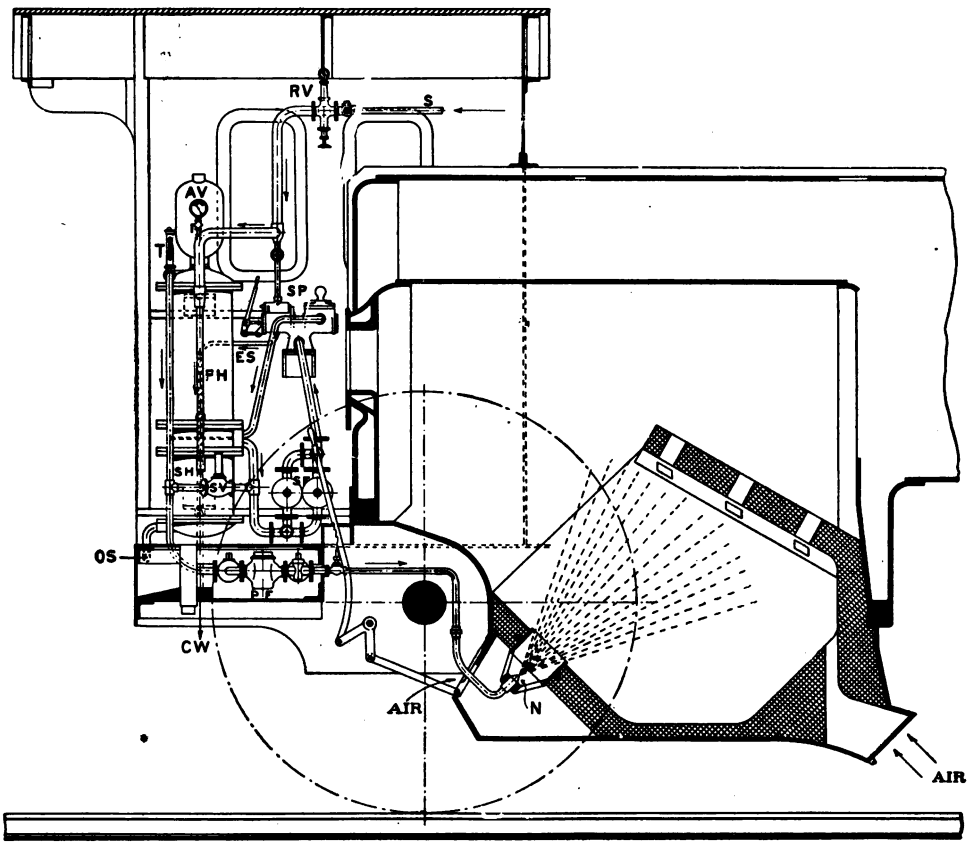


FIG. 160. OIL FIRING ON LOCOMOTIVES.

valve, *N* nozzle, *PH* pressure heater, *RV* reducing valve, *S* steam pipe, *T* thermometer, *PF* pressure filters, *SF* suction filters, *SH* suction heater and *SP* steam pump.

We will now say a few words about steam-jet oil burners which are used in small plants and in places where the fuel is heavy and

viscous. In these burners the fuel is divided into fine drops by means of a jet of steam, a mixture of air-jet and steam, or an air-jet. The plain steam jet should be used for heavy fuel like tar.

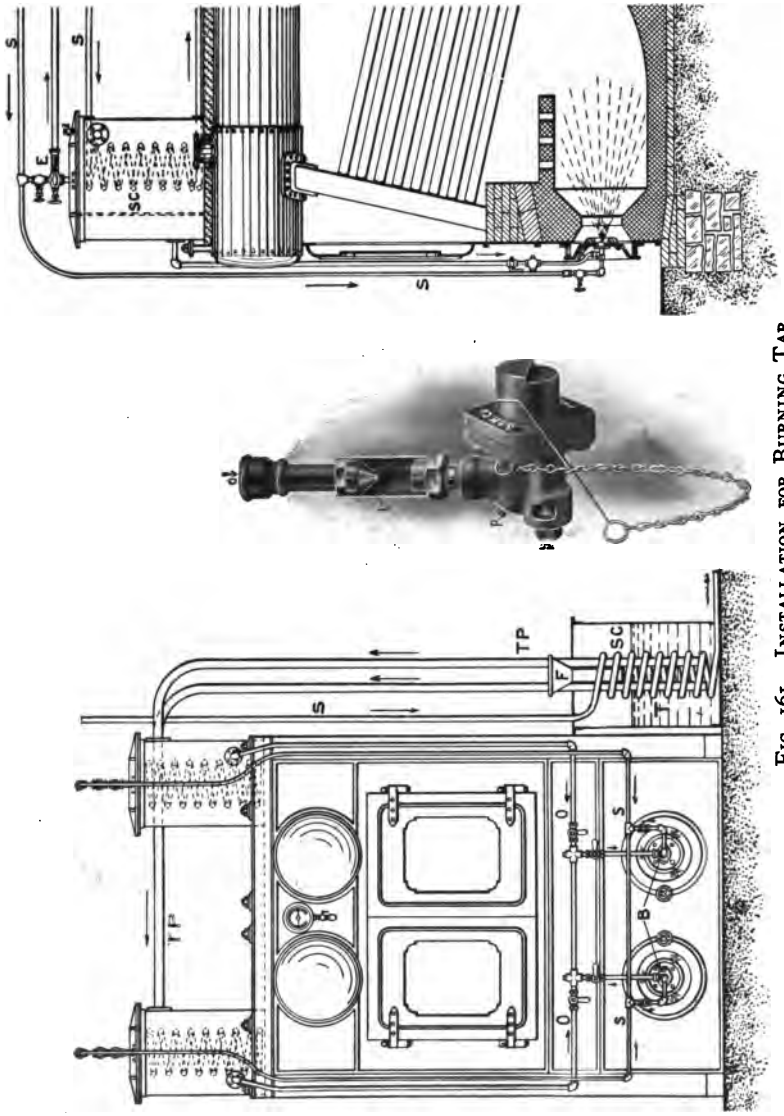


FIG. 161. INSTALLATION FOR BURNING TAR.

For light fluids, a mixed jet (steam and air) or air only can be used. A steam-jet oil burner for tar and also an installation is shown in Fig. 161. In the cut showing the burner, *L* is a movable

sleeve, *O* the oil supply, *P* a plug for cleaning and *S* the steam pipe.

In the installation *B* is the steam-jet burner, *E* the steam exhausters, *O* the oil pipe, *S* the steam pipe, *T* the tar, *SC* the steam

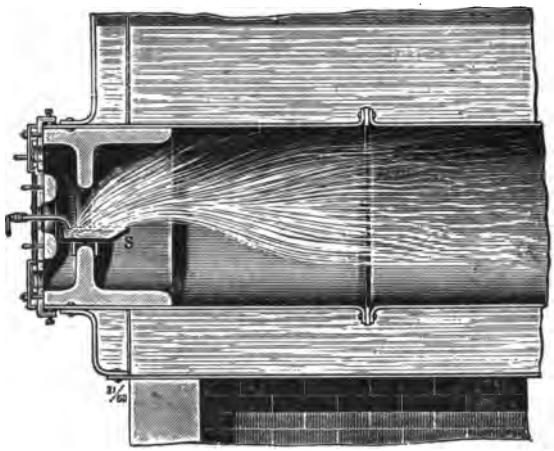


FIG. 162. STARTING THE FIRE.

coil for heating and *TP* the air pipe. The tar is lifted to the tank on top of the boiler by means of a steam-jet exhauster and flows from the tank to the burner by gravity. The oil should be heated

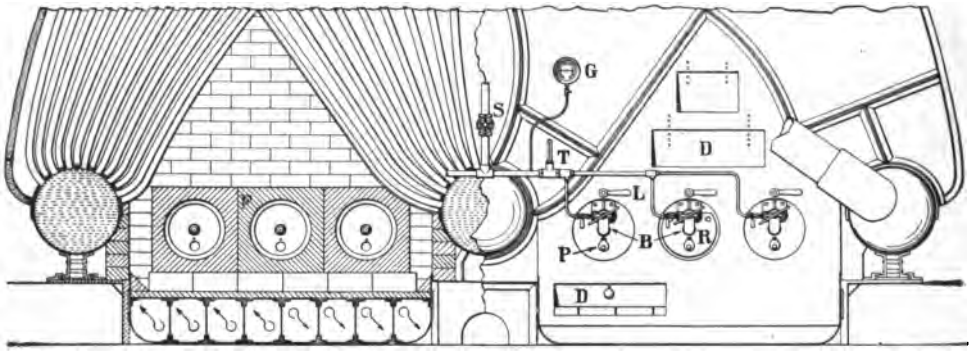


FIG. 163. TORPEDO BOAT EQUIPPED WITH OIL FIRING.

in the tank to about 150° Fahr. The flow of the fuel oil is regulated by means of cocks.

Fig. 162 illustrates the starting of the fire. A scoop or tray containing oil is mounted on the fire brick and the oil is ignited, the temperature of the boiler rising slowly and continuously.

TABLE XXVI.

No.	Quantity of Liquid Sprayed per Hour. Gallons.	Minimum Diameter of	
		Steam or Air Pipe. Inch.	Oil Pipe. Inch.
1	12	3/8	3/8
2	25	3/4	3/4
3	50	3/4	3/4
1	15	3/8	3/8
2	30	3/4	3/4
3	60	3/4	3/4

If there is steam in the boiler, the plant is started as follows: Full draft is put on so that all gases which might have remained in the fire-room will draw off. This is done to prevent explosion. Steam is now carried to the heaters and the pump started, so that the oil

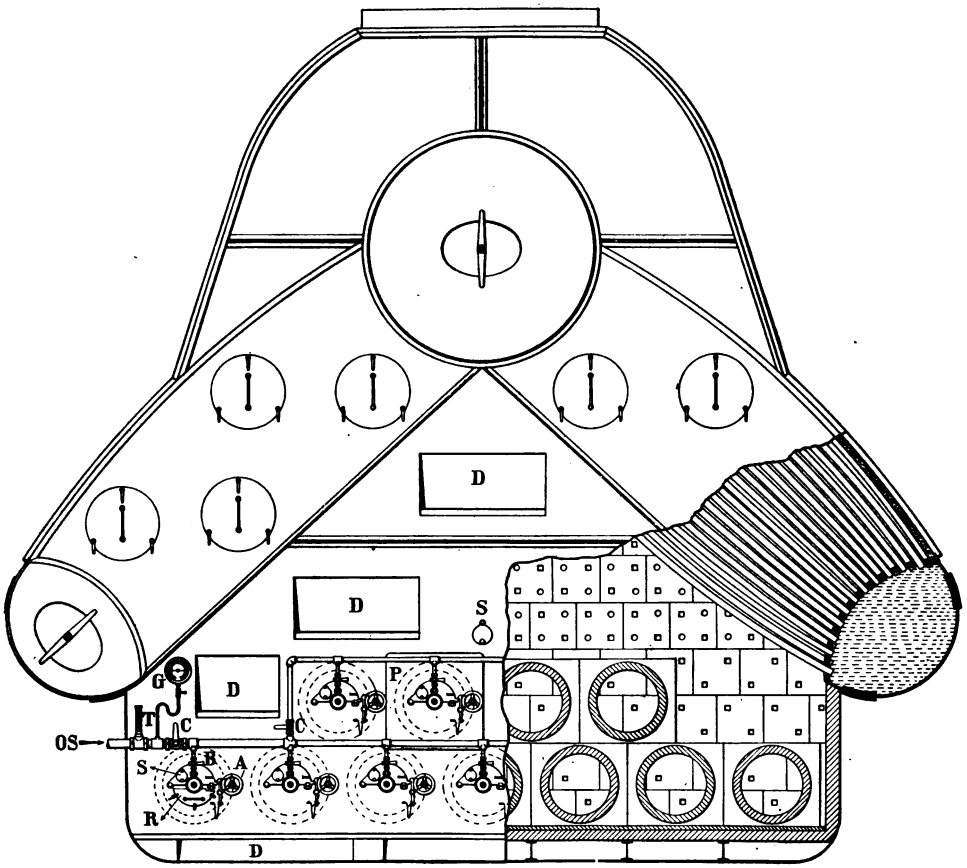


FIG. 164. INSTALLATION OF OIL BURNER.

circulates through the circular pipe until the oil has the proper temperature. Then the oil is ignited after the ring pipe has been shut off.

If there is no steam pressure on the boiler, the warming-up arrangement should be started. When starting the oil-firing plant, smoke will appear until the walls of the fire-room are sufficiently

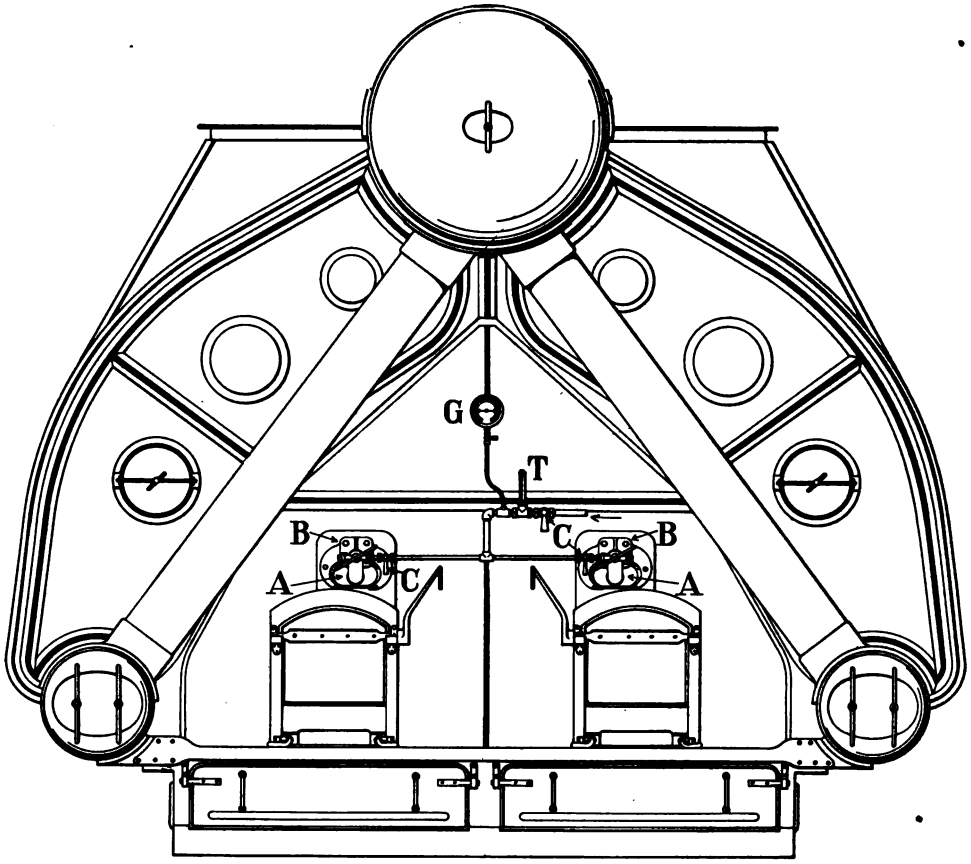


FIG. 165. ADDITIONAL OIL FIRING.

hot. When stopping the plant, the air admission must be shut off, in order to prevent excessive cooling of the boilers. Table XXVI. gives the capacities of steam-jet burners:

We return again to the centrifugal spray oil-burning system in order to describe a few installations on board of boats. This system

is at present widely used in the navies and merchant marine and its application is steadily on the increase. Fig. 163 shows a torpedo boat equipped with this system. *B* is the burner, *D* the air admission, *F* the fire-brick cylinders, *G* the gauge, *L* the handle for regulating the admission of air, *P* are glasses for observing the heat,

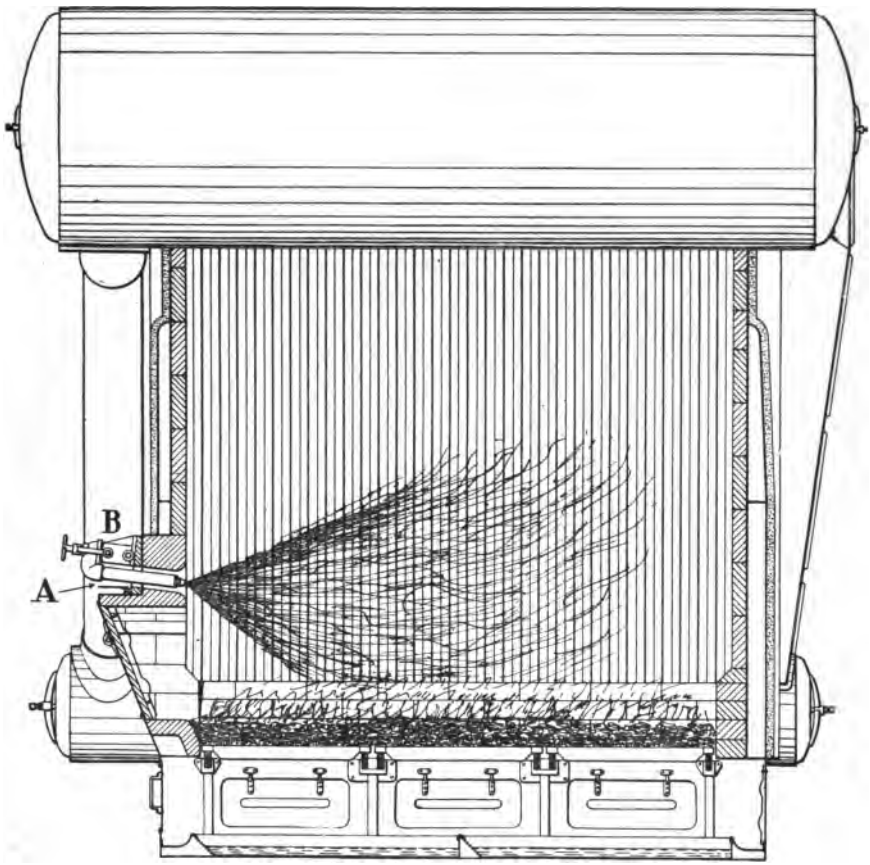


FIG. 166. ADDITIONAL OIL FIRING.

R the air register and *T* a thermometer. Twelve burners are provided, six on either front of the boiler. 0.86 to 1.07 pounds of oil are consumed per square foot of heating surface.

Another installation illustrating the arrangement of the burners is shown in Fig. 164. In order to effect an intimate mixture of the air with the oil, fire-brick cylinders are provided. Thereby the air is

forced to surround the injected oil and a proper contact between air and fuel is reached. The fire-brick checker work also acts as a heat storer and helps to keep the furnace at a high temperature.

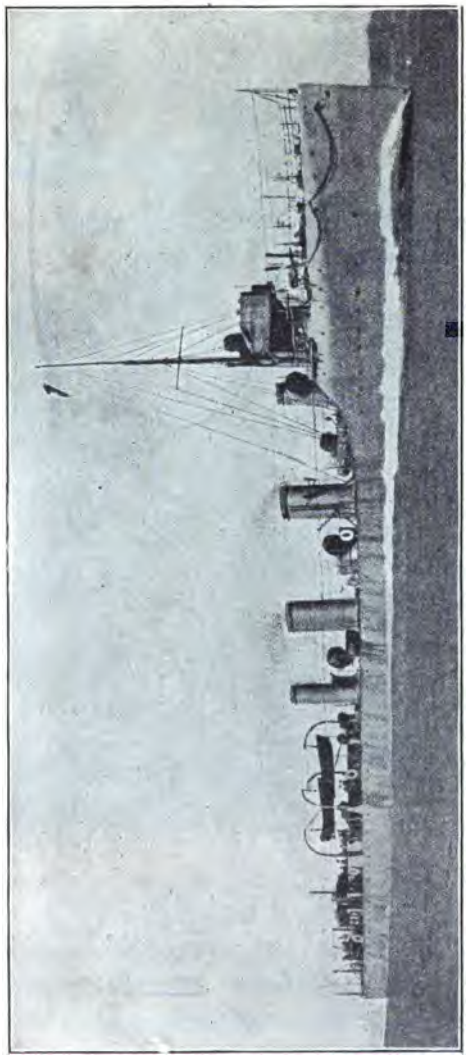


FIG. 167. TORPEDO BOAT DESTROYER EQUIPPED WITH OIL FIRING.

A is the hand wheel for regulating the air supply, *B* the burner, *C* the cock, *D* the admission of air, *G* the gauge, *OS* the oil supply pipe and *T* a thermometer.

This oil-firing system has also found extensive application in the navies as "additional firing," *i. e.,* for burning coal and oil at the

same time, in cases where the boilers have to be forced, and for burning oil alone whenever this should be convenient. Modern battleships of the various navies are equipped with such additional

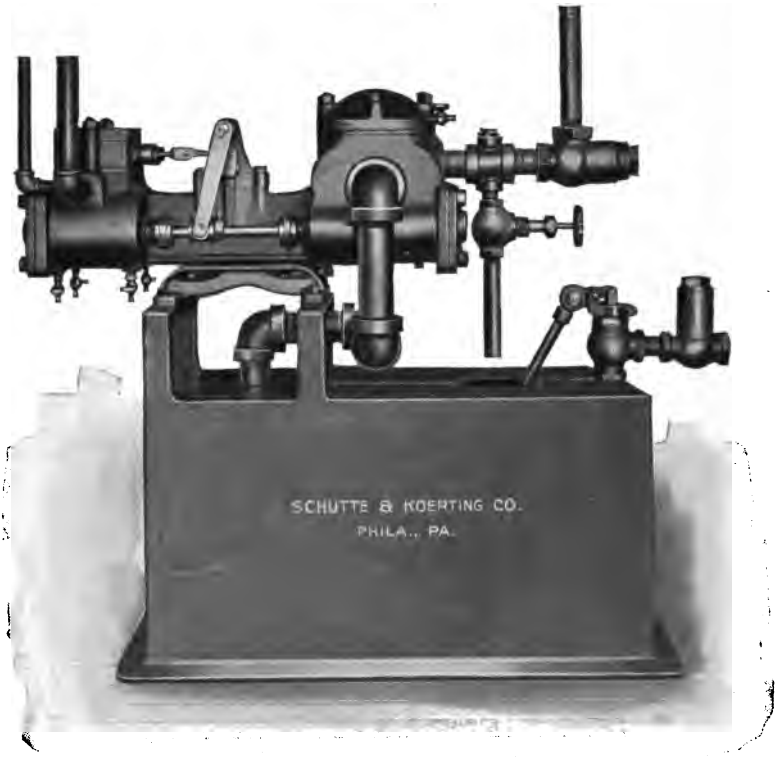


FIG. 168. STEAM-DRIVEN PUMPING OUTFIT.

oil firing. In the installation shown in Fig. 165 *A* is the admission of air, *B* the burner, *C* the cock, *G* the gauge and *T* the thermometer. In such installations (see also Fig. 167) the burners must not interfere with the feeding of the coal fire. They are therefore arranged either between the fire doors or over the fire doors, according to the construction of the boiler. As the space is usually very limited, the burner and air register is frequently combined in the construction, the regulation of air being accomplished by means of flaps.

Pumping Outfits for Spray Nozzles.

The pumping outfits used in connection with spray nozzles are either steam-driven, as shown in Fig. 168, or belt-driven, as shown in Fig. 169. These outfits consist of a pump, a water tank and float valve, a water-pressure balanced valve and two strainers, one in the supply, the other in the discharge pipe.

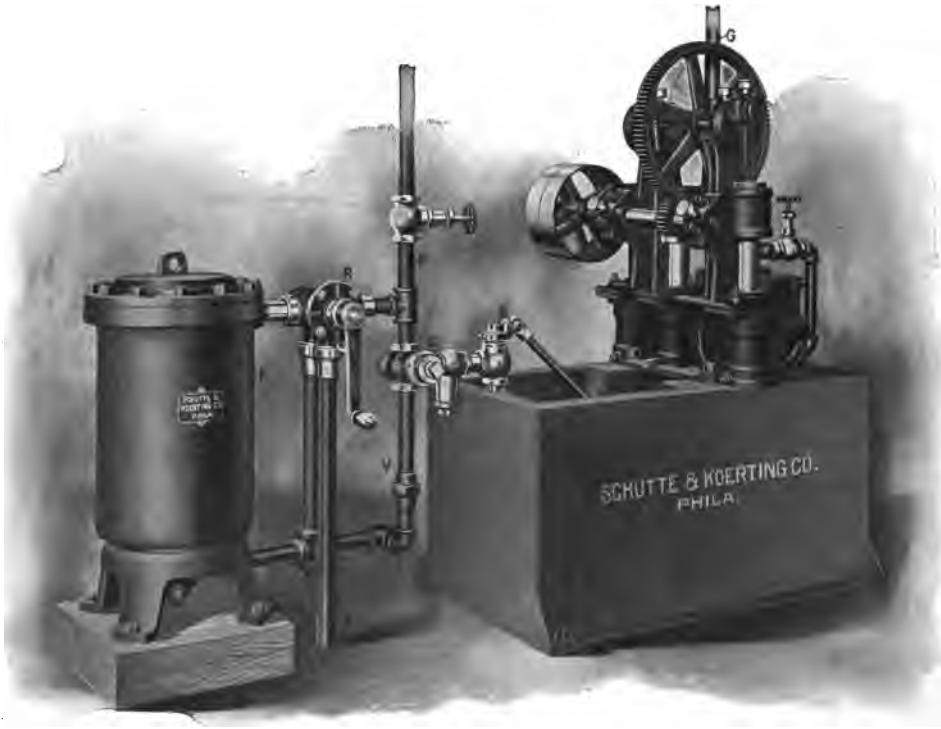


Fig. 169. Belt-driven Pumping Outfit.

The water-pressure balanced valve keeps up a uniform pressure at all times. It is to be recommended to use a pressure of 60 pounds. The capacity is regulated by increasing or decreasing the pressure and by cutting out a corresponding number of sprays.

Where the water is dirty a filter has to be installed. For clean water it is sufficient to have a strainer in the main supply and main discharge pipes.

FIFTH PART.

CONDENSERS.

General Remarks.

In order to economically utilize the fuel in steam plants it is necessary to effect a high expansion of steam. For this purpose a vacuum is required in which the steam is exhausted and condensed, after it has done its work in the engine cylinder or turbine. Among the different types of condensers built for this purpose the jet condensers are the simplest and most reliable.

Fig. 170. Eductor Condenser.

In the jet condenser the exhaust steam enters with the cooling water into the condensing chamber, where the steam is condensed by the water. This physical process being completed, the water jet together with the condensed steam and the non-condensable gases, has to be discharged against the pressure of the atmosphere. This mechanical work is performed by the same water jet, which, in order to produce this effect, has to enter the condensing chamber in a solid jet. The latter, after the steam is condensed, enters the discharge cone or tail-pipe with such a velocity that it overcomes the pressure of the atmosphere, being strong enough to expel the air. In order to keep the jet straight it is surrounded by a combining tube, in which ports are provided at a suitable angle. The steam from the condensing chamber entering through the ports is condensed by the jet. The holes are cut in an angle tending to give the water a high velocity. These condensers are built either as eductor or induction condensers. The eductor condensers may be either of the single-jet or multi-jet type. Each type has its separate and distinct applications.

Single-Jet Eductor Condensers.

The construction and working of this condenser will be easily understood from Figs. 170, 171 and 172. Fig. 170 gives a sectional view, 171 shows the way of connecting. In the latter cut *A* is the condenser, *B* the water check, *C* the free exhaust, *D* the strainer, *E*

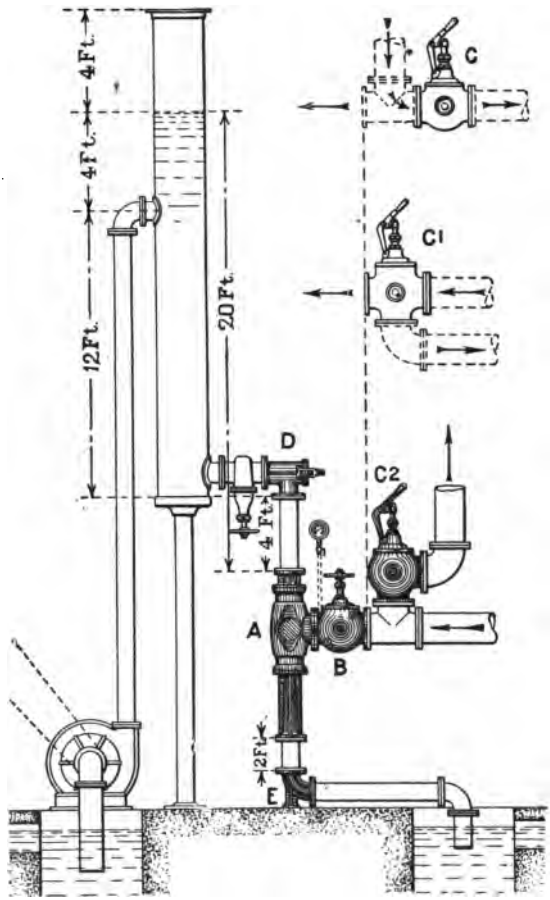


Fig. 171. Attachment of Condenser.

the foot elbow, C^1 and C^2 the variations of the free exhaust. Fig. 172 illustrates the condenser with fittings.

The dimensions with reference to Fig. 172 are given in Table XXVII. Table XXVIII. shows the capacity and size of connections.

TABLE XXVII.

Condenser.					Valves and Fittings.					
Size in Inches.	*A*	*B*	*C*	*D*	Center to Face.	Diam. of Flange.	Diam. of Bolt Circle.	No. of Bolts.	Diam. of Bolts.	Thick. of Flange.
1½	6¾	5¼	2¾	2	3⅜	5	4	4	½	½
2	9	6¼	3¼	2½	3¾	6	4¾	4	½	9/16
2½	10¾	7	3¾	2¾	4¼	7	5½	4	½	⅝
3	12½	8	4⅛	3¼	4¾	7½	6	4	½	11/16
3½	15	10	4½	3¾	5¼	8½	7	4	½	¾
4	17½	11	5	4	5¾	9	7½	4	⅝	13/16
4½					6	9¼	7¾	8	⅝	13/16
5	21½	13	5½	4½	6½	10	8½	8	⅝	⅞
6	25¾	15	6½	4¾	7	11	9½	8	⅝	⅞
7	30½	17	7¼	5	8	12½	10¾	8	⅝	15/16
8	35½	19	8	5¼	8½	13½	11¾	8	⅝	1
9	41	21½	9	5¾	9½	15	13¼	12	⅝	1
10	46¼	23½	10	6½	10½	16	14¼	12	¾	1 1/16
12	53	27	11	7	12	19	17	12	¾	1⅛
14	61¾	30	12	7¾	14	21	18¾	12	⅞	1 3/16
16	70	34	14	8¼	16	23½	21¼	16	⅞	1¼
18	80¼	38½	15	10	18	25	22¾	16	1	1 5/16
20	90	43	18	11¼	20	27½	25	20	1	1⅜
24	108	51	21	12½	24	32	29½	20	1	1 7/16

TABLE XXVIII.

Size Condenser. Diameter Exhaust.	Water Consumption per Minute. Maximum.		Diam. Water Supply and Discharge Pipe.	Approximate Horse-power for Evaporation per Horse-power per Hour.		
	Gallons.	Cubic Feet.		20 Lbs.	30 Lbs.	40 Lbs.
1½	15	2	1	15	10	7.5
2	26	3.5	1¼	26	17	13
2½	37	5	1½	38	25	19
3	52	7	2	52	35	26
3½	75	10	2½	75	50	38
4	112	15	3	112	75	56
5	165	22	3½	165	110	82
6	240	32	4	240	160	120
7	330	44	4½	330	220	165
8	450	60	5	450	300	225
9	600	80	6	600	400	300
10	750	100	7	750	500	375
12	1,050	140	8	1 050	700	525
14	1,425	190	9	1,425	950	712
16	1,800	240	10	1,800	1,200	900
18	2,400	320	12	2,400	1,600	1,200
20	3,000	400	14	3,000	2,000	1,500
24	4,500	600	16	4,500	3,000	2,250

Eductor condensers require a head of water of 20 feet, and work with absolute certainty under all kinds of load variations. The air and non-condensable gases are discharged with the water without the assistance of air pumps. The special advantages of these con-

densers can be defined as follows: Absence of air pumps, hence saving of power and lower cost of maintenance; full water openings, preventing any clogging up of the water supply; short exhaust pipes from the engine or turbine to condenser, hence no leaks in the exhaust pipe, as is frequently the case with barometric condensers; the low cost of these condensers permits the adoption of an engine for condensation during the summer, while during the winter the exhaust can be used for heating purposes.

Where surface or barometric condensers are used the installation of central condensing plants is often made imperative by lack of space, since in such a case a separate condensing plant cannot be installed for every steam unit, and as in these cases it is also desired to avoid the complication involved by separate condensers, each with a number of moving parts. Central condensing plants, however, have the disadvantage, that long exhaust mains and consequently frictional and leakage losses between condenser and engines can hardly be avoided, that it is difficult to locate the leak, that the vacuum on any single engine is affected by leakage on the others and that in the operation the constant manipulation of valves, usually of gate valves, is necessary.

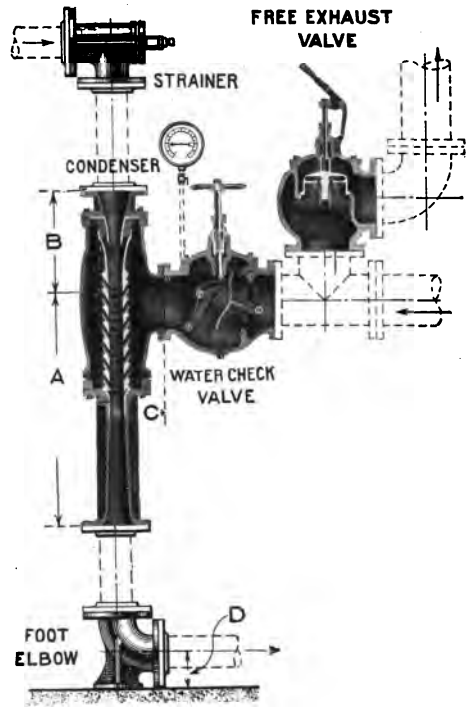


FIG. 172. CONDENSER AND FITTINGS.

The eductor condensers, on the other hand, have no moving parts and occupy such small space, that it is generally practicable to attach a separate condenser to each steam unit, so that the loss of vacuum between condenser and engine is reduced to a minimum.

We will now discuss the water requirements of the eductor condenser. With injection water at a temperature of 60° Fahr. and

barometer at 30 inches, this instrument will maintain a vacuum of 24 inches mercury column with a proportion of water to steam 25 to 1. In most instances the quantity of water used is of importance only in relation to the power required for operating the plant, and from this standpoint the eductor condenser compares favorably with the surface condensers.

For comparison, a compound condensing plant for a 1,000-horse-power engine may be taken. At a steam consumption of 20 pounds of steam per brake horse-power the plant would condense 20,000 pounds of steam per hour, and a 12-inch eductor condenser using 1,050 gallons of water per minute, would maintain a vacuum of 24 inches of mercury. The condenser is 8 feet long, and with 15 feet head of water and a discharge pipe 2 feet long, the total difference would be 25 feet and the actual horse-power required $(1{,}050 \times 25 \times 8.3) : (33{,}000) = 6.6$. An efficiency of 50 per cent. can be obtained with electrically driven centrifugal pumps with full allowance for motor-pump and dynamo losses. The actual B.H.P. required for working such a plant would be $(6.6 \times 100) : 50 = 13.5$ B.H.P., or less than 1½ per cent. of the power developed by the main engine. In this calculation no allowance is made for loss by friction in pipes or for gravity flow from the hot well, as similar allowances have to be made with any condensing plant.

The advisability of a separate condenser for each steam unit (excepting small engines) was already mentioned. However, if this cannot be arranged, a drum of sufficient area, into which a number of engines exhaust, can be provided and the condenser attached. Such a plant has the advantage of low cost and of simplicity, as compared to an installation of any other type of condenser.

The water is delivered advantageously from the pump into an intermediate overhead tank, fixed at suitable level to give the necessary head of water for the condenser, or the water may be delivered directly from a centrifugal pump into the condenser.

When an intermediate overhead tank is used, any air drawn in at the pump glands or at the joint or suction pipes escapes at the tank, and the vacuum is not affected as in the case when the air is delivered with the water directly into the condenser. The tank also affords the advantage that, when a number of condensers are used, any one of the pumping sets can serve for any of the condensing units, thus giving greater elasticity and security against breakdown.

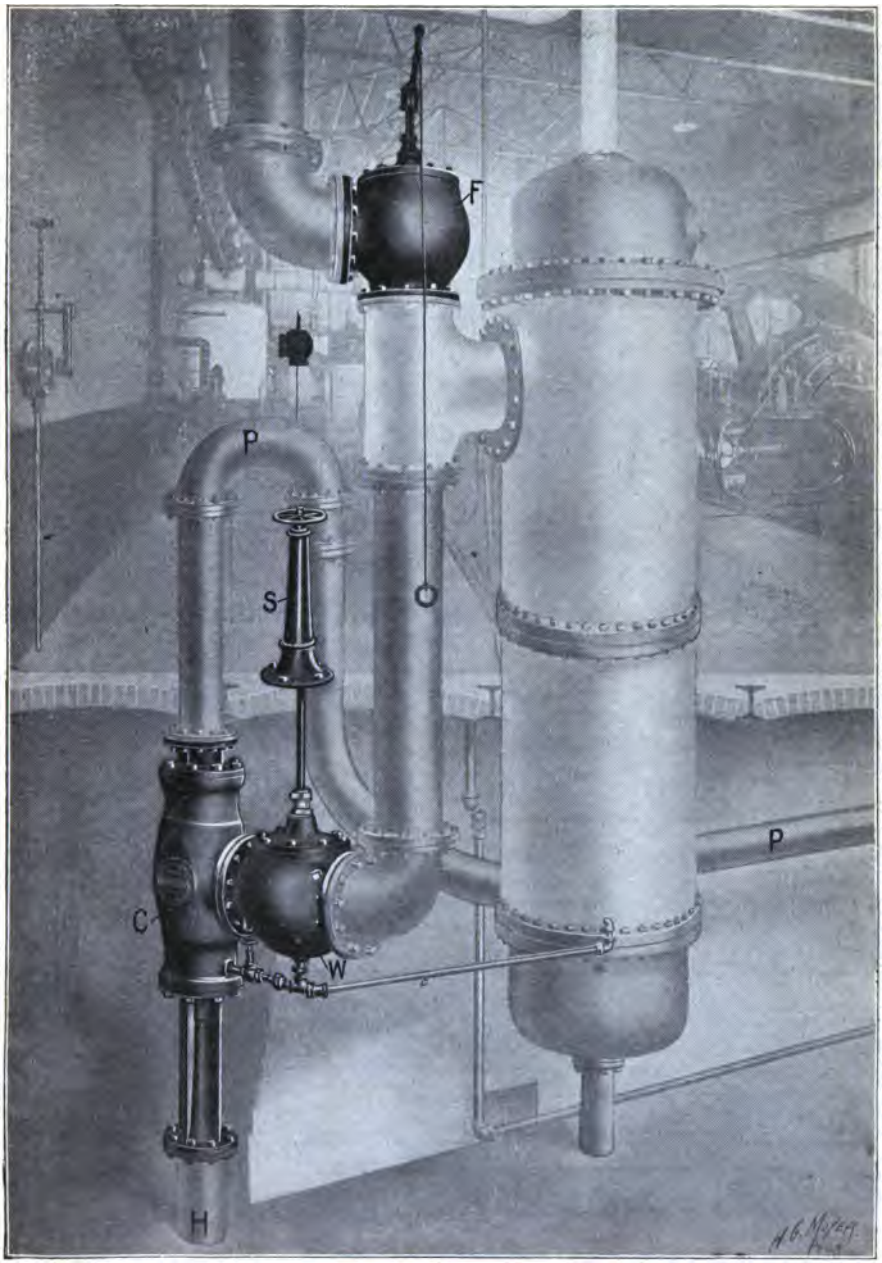


FIG. 173. CONDENSER ATTACHED TO ENGINE.

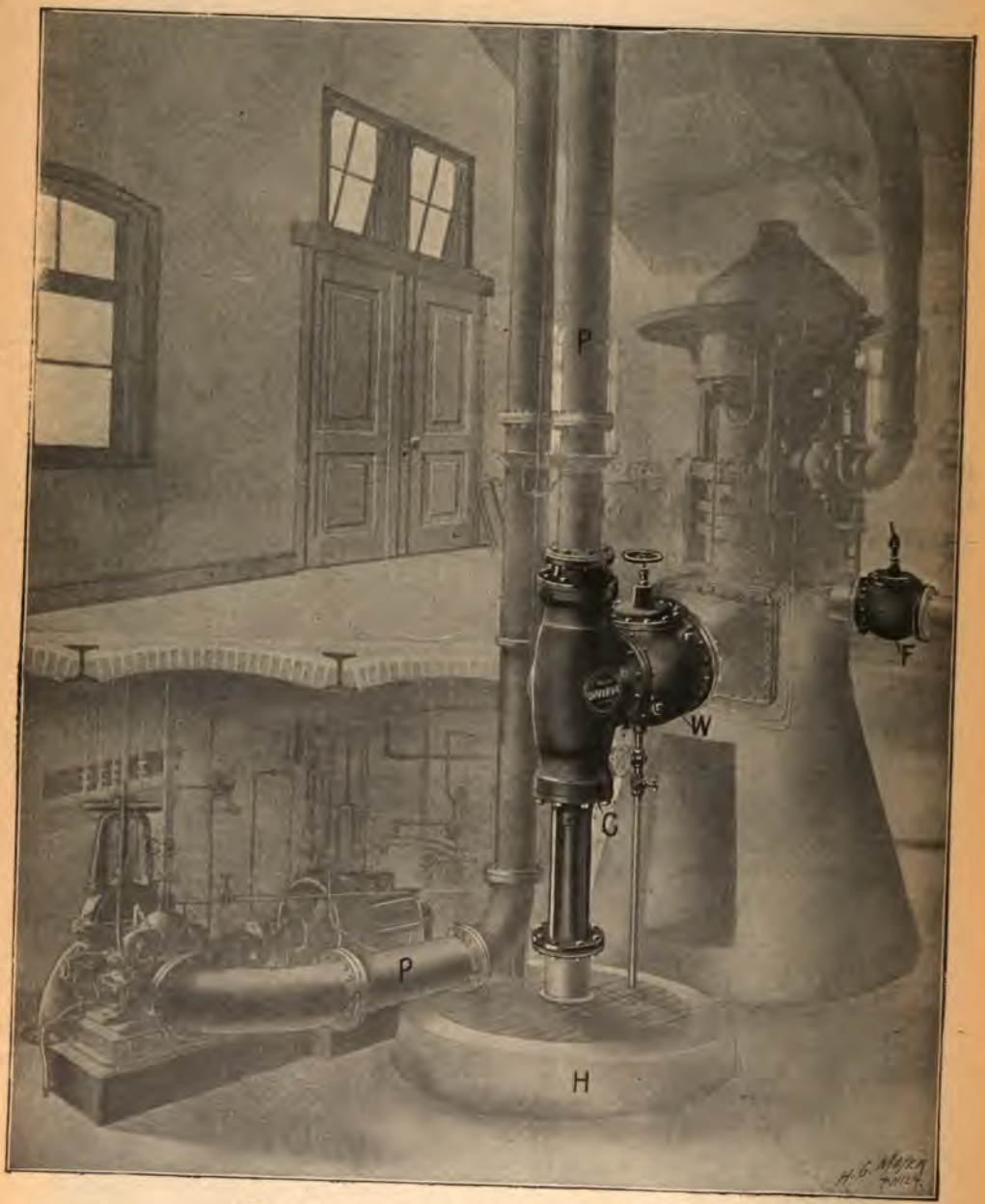


FIG. 174. CONDENSER ATTACHED TO TURBINE.

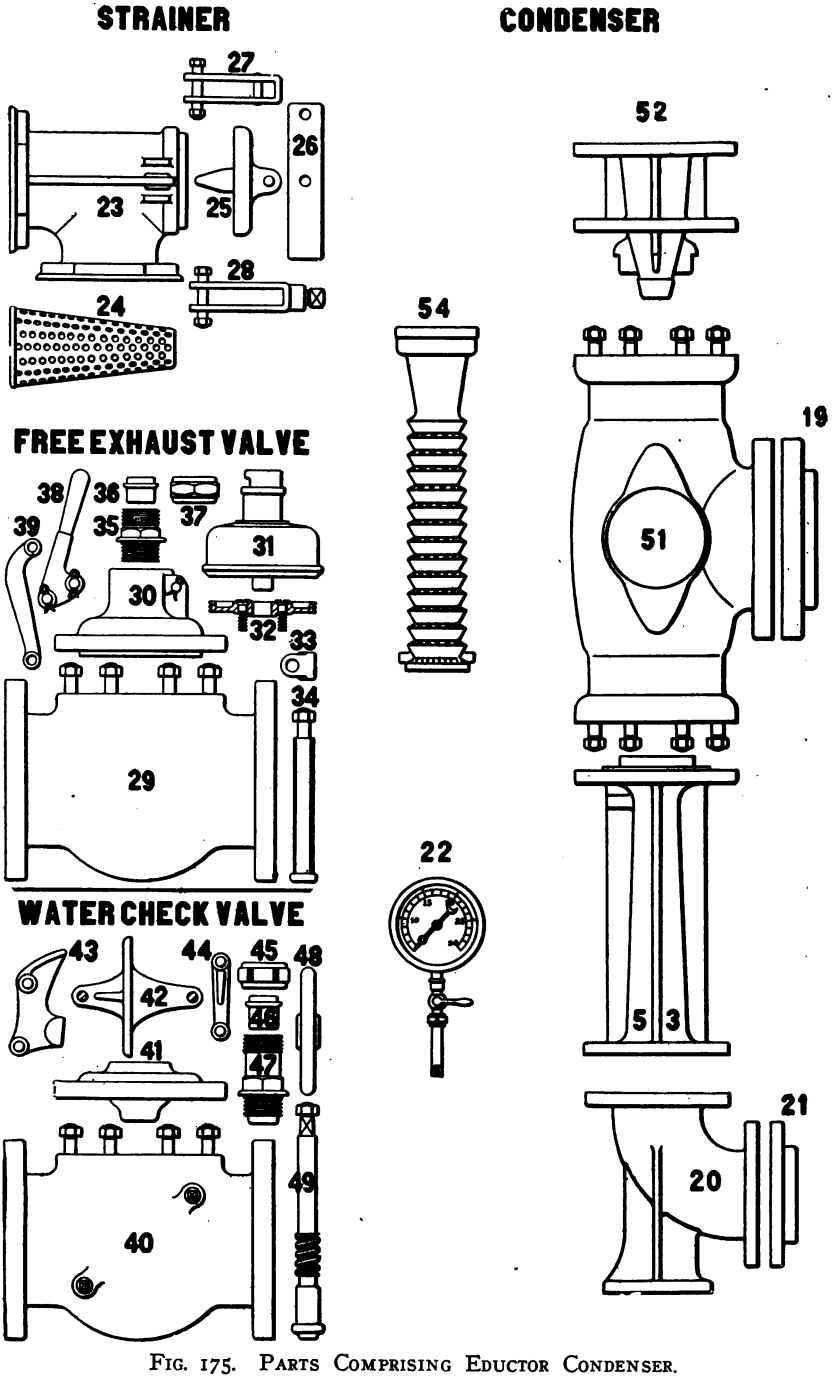


FIG. 175. PARTS COMPRISING EDUCTOR CONDENSER.

It has been mentioned already that electrically driven centrifugal pumps are an ideal means to procure the water supply for a condenser. However, where line shafting is available, belt- or rope-driven pumps may be used. In such a case the cost of the motors is saved, and a somewhat higher efficiency obtained than by electric drive. If none of these methods of pumping can be applied, centrifugal pumps driven by high-speed reciprocating engines, or by steam turbines, may be used. The exhaust steam formed can be utilized for heating boiler feed water. When reciprocating pumps are used the water has to be delivered into an overhead tank, or large air chambers have to be provided on the pump discharge, in order to produce an even pressure at the condenser inlets.

The condenser should be installed vertically, with a clear discharge—not less than two feet below the bottom flange of the apparatus—to the level of the water in the discharge sump or hot well. The end of the discharge pipe should be under water, unless there is a horizontal discharge main, and a trap to the water seal directly at the elbow under the condenser. Except with condensers of very large size, where special allowance has to be made for long suction or discharge pipes, a difference of level of 30 feet between supply and discharge will usually give the necessary pressure of water at the condenser, with full allowance for frictional losses.

If a gravity supply of water at sufficient pressure is at hand the vacuum secured by eductor condensers is clear gain, as no power, except the gravity, is consumed.

Fig. 173 shows an eductor condenser attached to reciprocating engine exhausting through heater. Fig. 174 shows a condenser attached to a turbine.

Fig. 175 illustrates the pieces comprising this condenser. *51* is the body; *52*, the water head; *53*, tail; *54*, combining tube; *19*, flange and bolts; *20*, foot elbow; *21*, flange; *22*, vacuum gauge; *24*, the strainer; *23*, its body; *25*, its cover; *26*, its bar; *27*, its hinge strap, and *28* its screw strap. Free exhaust valve: *29*, body; *30*, cover; *31*, valve; *32*, piston; *33*, trunnion; *34*, spindle; *35*, stuffing box; *36*, follower; *37*, coupling; *38*, lever; *39*, link; water-check valve; *40*, body; *41*, cover; *42*, valve; *43*, front link; *44*, back link; *45*, coupling; *46*, follower; *47* stuffing box; *48*, hand wheel; *49*, spindle.

Multi-Jet Eductor Condensers.

The single-jet condensers give excellent results for vacua up to 26 inches of mercury; but for large units and for the high vacua required in turbine plants, where the water consumption is very considerable, the multi-jet condenser, as shown in the sectional cut, Fig. 176, is to be preferred. This condenser, while consuming much less water, still maintains the essential qualities of the single-jet condenser.

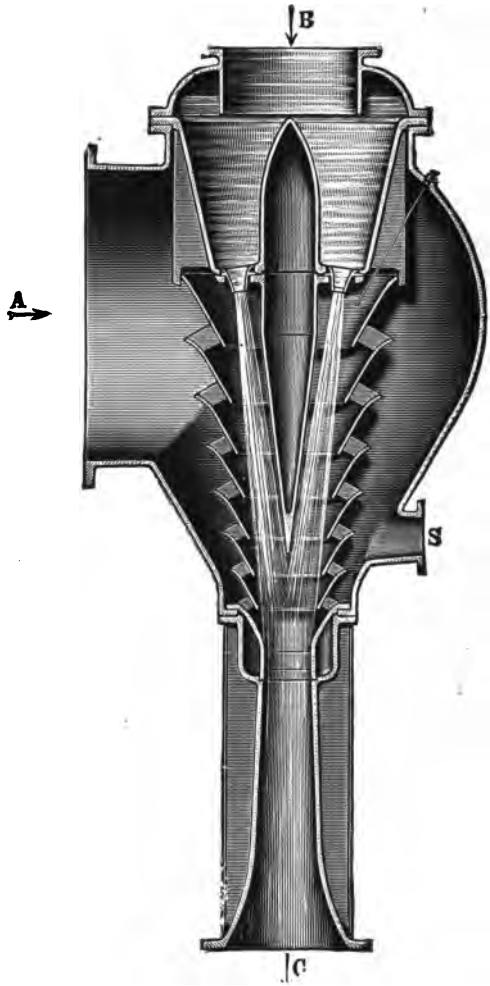


Fig. 176. Multi-Jet Eductor Condenser.

With the latter a single condensing jet is used, which, as we have already mentioned above, passes centrally through a long cylindrical tube. This tube is provided with perforations for the passage of the exhaust steam from the condensing chamber to the jet. The holes are drilled obliquely, directing the steam at a suitable angle, so that it impinges on the condensing jet in the direction of the flow. The steam which strikes the condensing jet at high velocity is condensed, and the particles of water into which it is converted cut into the jet with the kinetic energy due to the steam velocity, and contribute to the momentum, which is needed in order to discharge the jet together with the entrained air and the non-condensable gases against the resistance of the atmosphere.

The multi-jet condenser works on the same principle, but has, instead of one central condensing jet, a number of converging jets, which, in the lower part of the condensing tube, meet and form a single jet. This tube is cast in one piece and consists of a series of concentric nozzles of gradually diminishing bore. The steam flows through the annular passages between the nozzles which act as guides, so that it impinges at a suitable angle on the condensing jets.

The multi-jet condensers are considerably shorter than the single-jet apparatus of equal capacity, but, notwithstanding this fact, the area of contact between steam and water is larger. A further advantage is gained by the shape of the condensing tube, which in vertical section is an inverted cone. In the upper part of the tube the steam is in contact with the coldest water, and the condensation is very intense, so that in this part more steam is condensed per unit of area of contact, than in the lower part, where the water is hotter.

It will be seen that with the conical tube the sectional area of the steam passages increases from the bottom upwards, whereby the sectional area of the ports is kept proportional to the volume of steam which is to go through. Therefore the steam velocity is nearly constant from the top to the bottom of the tube, and the drop of vacuum between the interior of the tube and the exhaust chamber can be reduced to a minimum.

It is clear that there must be a higher absolute pressure, or, in other words, lower vacua in the exhaust chamber than in the interior of the tube, as otherwise there would be no flow of steam through the ports to the condensing water jets.

A difference in the vacuum equal to one half inch of mercury column is sufficient with a multi-jet condenser maintaining 28 inches mercury vacuum, and the actual vacuum obtained is therefore only one half inch lower than the highest theoretical vacuum as determined by the discharge temperature. The proportion of water to the quantity of steam condensed is, for equal vacua, with these condensers practically the same as with surface condensers. The advantages of the multi-jet condensers are the same as of the single-jet condensers, viz., no moving parts, small space, no attention and absence of air pumps.

To insure satisfactory working under all conditions of load variation it is only necessary to supply the water to the condensers

at a pressure, at the level of the water inlet flanges, equal to 21 feet water column, or say, 9 pounds per square inch. When no gravity supply is available it is necessary to use a circulating pump, and if a motor- or belt-driven centrifugal pump be used, the water may be

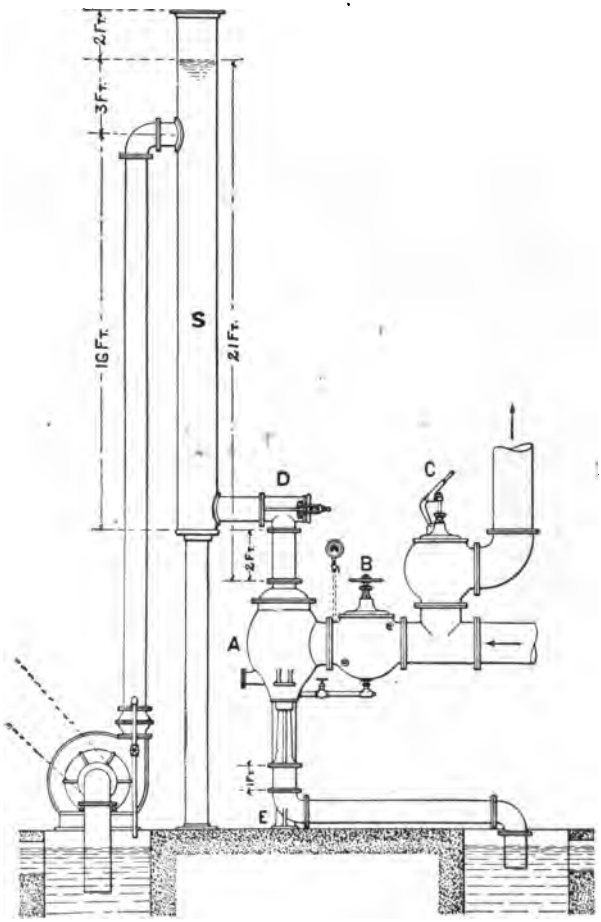


FIG. 177. INSTALLATION OF CONDENSER.

delivered to the condensers as shown in Fig. 178. A safer way to get rid of the air is by the use of a standpipe, as illustrated in Fig. 177. *A* is the condenser, *B* the water-check valve, *C* the free exhaust valve, *D* the strainer, *E* the foot elbow and *S* the standpipe. In the installation shown in Fig. 179 *C* is the condenser, *D* the discharge, *F* the free exhaust valve, *P* the pressure pipe and *S* the strainer. The dotted lines represent a barometric condenser.

Taking, as example, a 1,000 K.W. reciprocating set, using at full rated output 20,000 pounds of steam per hour, a multi-jet condenser, using 72,800 gallons of water per hour, would maintain 26 inches mercury vacuum when dealing with this weight of steam with water supplied at a temperature of 60° Fahr. and barometer 30 inches. The condenser would be 6 feet long and the water would

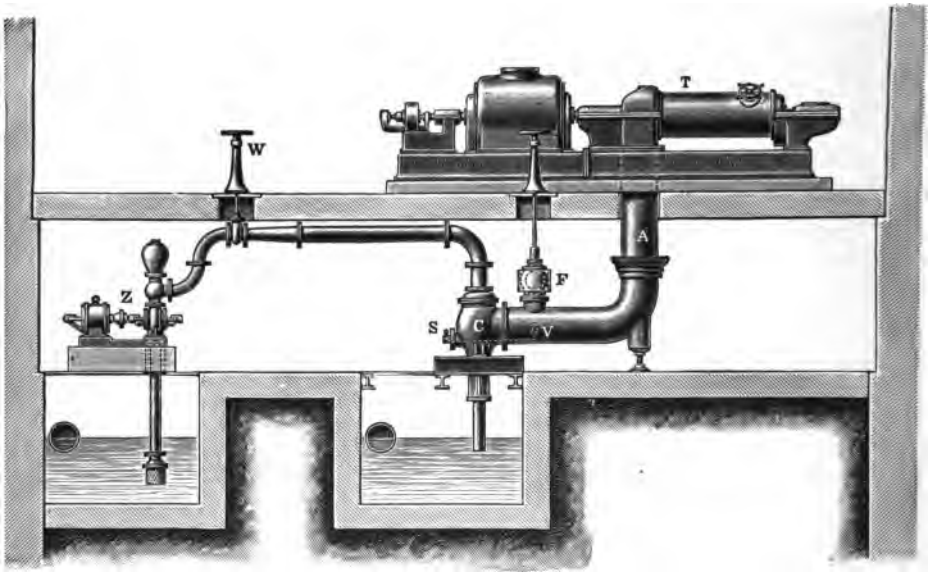


FIG. 178. TURBINE AND MULTI-JET CONDENSER.

have to be delivered at a pressure equal to 21 feet head at the level of the inlet flange. The lift for the circulating pump would be therefore 6 feet plus 21 feet plus allowance for friction losses and difference of level between the pump intake and the condenser outlet flange.

Assuming an allowance of 6 feet would suffice for these last items, the pump duty would be 1,200 gallons per minute through a total lift of 33 feet, representing 9.9 water horse-power. The combined efficiency of the motor-driven centrifugal pump should be not less than 60 per cent. and the power required would be 11 K.W., or 1.1 per cent. of the full load output of the set.

With a turbine of the same size requiring a vacuum of full rated output of 28 inches of mercury a condenser using 106,024 gallons of water per hour would be needed, and the power required would be $1.1 \times 106{,}024/72{,}800 = 1.6$ per cent.

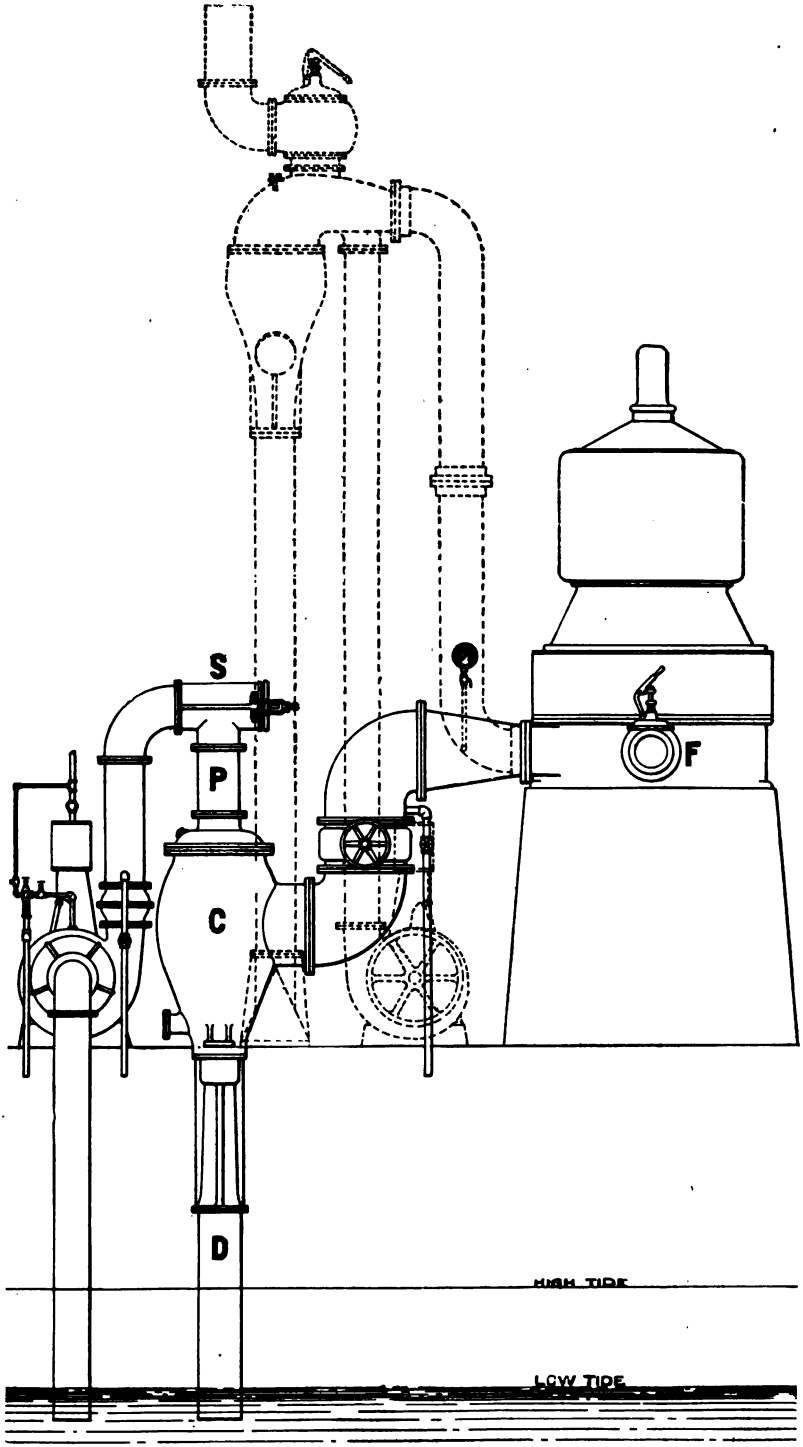


FIG. 179. CONDENSER INSTALLATION.

With an exhaust steam turbine of the same capacity, using, say, twice the weight of steam per kilowatt output, the power required for working the condenser with 28-inch vacuum would be 3.6 per cent. of the full load output. With circulating water at a temperature of 70° Fahr., the power required, other conditions being as above, would represent about 2 per cent., 5 per cent. and 10 per cent. of the full load outputs, and at 75° Fahr. about 3 per cent., 7½ per cent. and 15 per cent. If recooled water has to be used for condensing, it is important that efficient cooling arrangements be adopted, as with water at temperatures above 75° Fahr. the quantity of circulating water and the power required for working the condensing plant becomes disproportionately high.

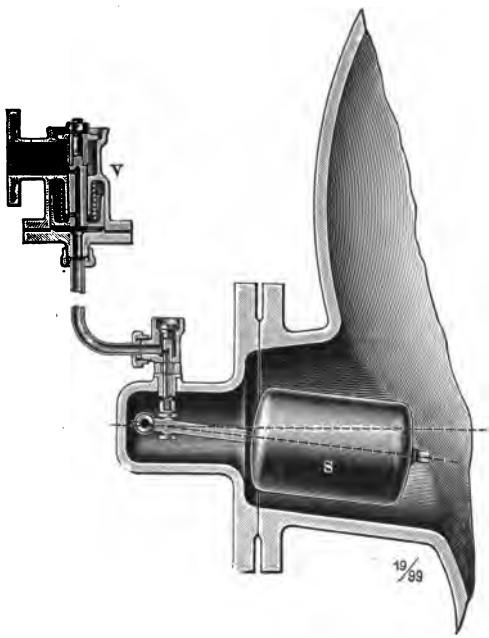


FIG. 180. VACUUM BREAKING ARRANGEMENT.

In order to prevent water from passing from the condenser into the turbines to which they are attached, a vacuum-breaking device as illustrated in Fig. 180 is used. The air admission valve *V* is connected to the exhaust pipe as near to the turbine as possible. Under normal working conditions the valve is held closed by the atmospheric pressure and by the spring pressing on the piston, which is attached to the valve spindle. A channel in the spindle connects the small chamber above the piston with the exhaust pipe, while a small pipe connects the lower side of the piston to the exhaust chamber of the condenser, so that the pressure on both sides of the piston is practically balanced.

If, for any reason, water rises in the condenser exhaust chamber, the float attached thereto opens the small relay valve, and air admitted through this valve presses on the lower side of the piston and, opening the main air valve, breaks the vacuum.

The air admitted into the exhaust connections passes to the condenser and clears the water from the exhaust chamber. Then the float drops and closes the relay valve, and, the pressure on the top and bottom of the piston being again equalized, the air admission valve is automatically closed by the spring. By the adoption of this automatic vacuum breaker the necessity for non-return valves in the exhaust connections is removed, and the inevitable drop of vacuum between the condensers and the engines or turbines due to friction in such valves is avoided.

Wherever practicable, a separate condenser for each steam unit should be adopted, as was already stated, but if this cannot conveniently be arranged, the steam from two or more engines or turbines may be carried to a central condenser.

The condensers work quite well in parallel, and for units above 5,000 H.P. it may, in some cases, be preferable to use two condensers (twin connection) instead of a single large apparatus.

For large installations it is usually better to have a common water supply main with branches to each condenser, the circulating pumps being installed in a separate pump house.

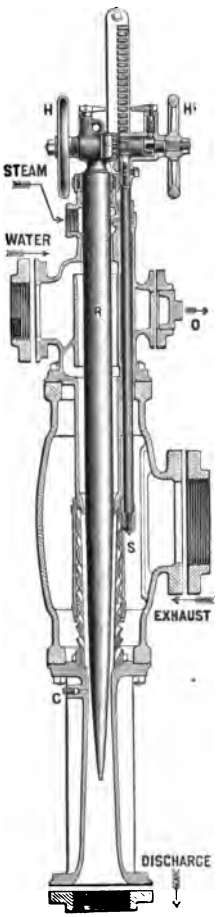


FIG. 181. INDUCTION CONDENSER.

INDUCTION CONDENSERS.

Induction condensers lift their own water supply and can be used only in connection with engines subject to load variation at regular and not frequent intervals. The vacuum is created by the condensation of the exhaust steam on a column of moving water, which is induced and maintained by the impact action of the exhaust steam through passages inclined in the direction of the current, thus assisting a natural fall of water, if there be such, or maintaining it unaided, if water has to be lifted from a lower level.

The induction condenser, Fig. 181, is equipped with a regulation of water supply and with a sleeve to cover the ports of the combin-

ing tube according to the steam consumption. Corresponding to the load of the engine, the water ram as well as the sleeve are set, and remain in this position as long as the engine runs under the conditions for which the condenser is set. This condenser is also highly adaptable where only a certain head is at disposal, whereas the rest of the water has to be supplied by the action of the exhaust steam itself.

The head of the condenser can be turned at right angles or in any direction admissible by the bolt spacing; so as to be most convenient for pipe connections or for handling.

When all the water is supplied under pressure, the tap opening marked "steam" and also the opening *C* are blanked. When water is taken under suction, and pressure water used for starting at inlet marked "steam," the opening *C* is blanked. When water is taken under high suction and steam used for starting, then a check valve is attached to opening *C*, and the overflow pipe so connected that it discharges free or into the main discharge pipe.

The location and connection of the condenser depends upon the water supply and the nature of the work of the engine. If the

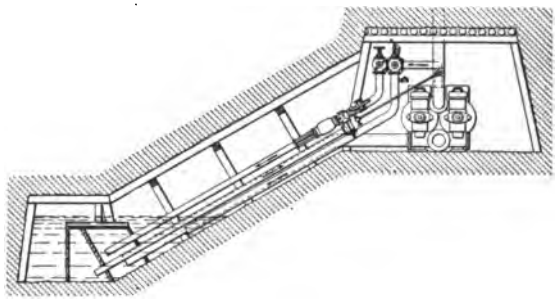


FIG. 182. CONDENSER ON MINE PUMP.

water can be supplied under pressure or if it can be obtained flowing to the condenser, it should be so arranged. When the water supply has to be taken under suction, the following conditions must prevail: (1) For engines working at uniform load the condenser can take its full water supply under suction up to a height of 16 feet, this height being measured from the supply water level to the inlet on the condenser. (2) For engines working with slightly variable load the condenser will take two thirds of its supply under suction up to 16 feet, if the rest is supplied at a pressure of 10 pounds or more.

In the latter case the pressure water is connected to the head of the condenser at the inlet marked "steam."

Figs. 182 and 182A show the installation of a condenser on mine pumps, Fig. 183 the side elevation of a condenser on a steamboat.

This condenser is also built with automatic discharge valve to take the water supply from a sump and to discharge it automatically into the suction pipe of the pump. This arrangement is particularly desirable in deep mines having a great discharge height and consequently a greater volume of exhaust in proportion to the volume of water pumped. If, under these conditions, the discharge from the condenser were returned to the sump, the temperature of the sump water would greatly increase, causing annoyance, damage to the timber and a decrease of the efficiency of the condenser. By discharging directly into the suction of the pump, the warm water is removed as it is produced, and the sump water remains cool.

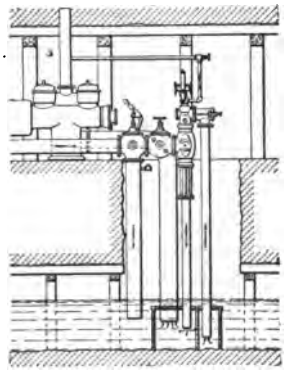


FIG. 182A. CONDENSER ON PUMP.

If steam would enter the pump through an accidental stoppage of the pump or the condenser, the action of the pump would be interfered with. This danger, however, is entirely eliminated by the

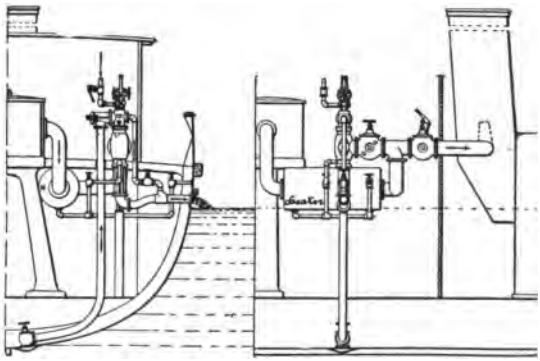


FIG. 183. CONDENSER ON STEAMBOAT.

automatic action of the discharge valve *Y*, see Fig. 184, which closes when the vacuum in the condenser is destroyed, while the condenser is able to restart through valve *X*. As soon as the condenser

resumes its action, the valve Y will open automatically, diverting again the discharge from the condenser into the pump suction. In the illustration Z is the condenser, H the free exhaust valve, W the water-check valve (safeguard against a backflow of water when

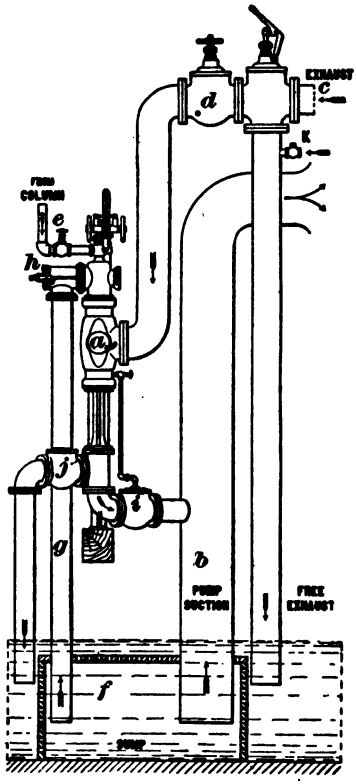


FIG. 184. CONDENSER WITH AUTOMATIC DISCHARGE VALVE.

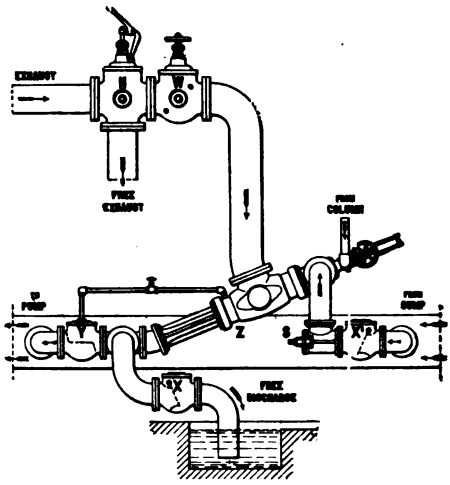


FIG. 185. CONDENSER WITH AUTOMATIC DISCHARGE VALVE.

starting and stopping the engine), S the basket strainer, Y the automatic discharge valve, X the discharge relief valve, X^1 the suction check and K the air check.

Another installation is shown in Fig. 185. Z is the condenser, W the water-check valve, H the free exhaust valve, S the basket strainer, Y the automatic discharge valve, X the discharge relief check and X^1 the suction check. The attachment of the discharge is near the pump, that of the suction near the sump. This arrangement is particularly suitable if the pump is at a great distance from

the sump, as thereby the necessity of providing long discharge and supply pipes for the condenser is avoided. The vacuum in the pump suction must not be greater than the vacuum in the condenser.

The condenser can be started before the engine is in operation, or it may be started while the engine is exhausting through the free exhaust valve. However, it is preferable to start the condenser first, so as not to disturb the free exhaust valve.

Directions for starting, Fig. 186. (1) All pressure water at *A*, *B* and *C* blanked. In order to start, the water is turned on at *A* and the engine started. In order to stop, the engine is stopped and *A* closed. (2) Suction *A* open; one third pressure water at *B*; *C* blanked. To start, pressure water is turned on at *B*, the engine is started and *B* closed. In order to stop, the engine is stopped. (3) Suction *A* open; pressure water or steam at *B* and overflow check at *C*. In order to start, pressure water or steam is turned on at *B*, the engine is started and *B* closed. In order to stop, the engine is stopped.

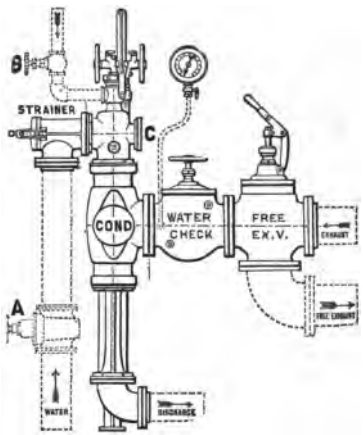


FIG. 186. CONNECTIONS TO CONDENSER.

Fig. 187 shows the parts comprising a condenser. *1* is the body; *2*, the water head; *3*, the tail; *4*, the water nozzle; *5*, the combining tube; *6*, the sleeve; *7*, the ram; *8*, the sleeve rod; *9*, crosshead for ram; *10*, crosshead for sleeve; *11*, pinion shafts; *12*, hand wheels; *13*, follower; *14*, coupling; *15*, gland; *16*, guides; *17*, bolts; *18*, flange and bolts; *19*, flange and bolts; *20*, foot elbow; *21*, flange and bolts; *22*, vacuum gauge. Strainer: *23*, body; *24*, strainer; *25*, cover; *26*, bar; *27*, hinge strap; *28*, screw strap. Free exhaust valve: *29*, body; *30*, cover; *31*, valve; *32*, piston; *33*, trunnion; *34*, spindle; *35*, stuffing box; *36*, follower; *37*, coupling; *38*, lever; *39*, link. Water check valve: *40*, body; *41*, cover; *42*, valve; *43*, front link; *44*, back link; *45*, coupling; *46*, follower; *47*, stuffing box; *48*, hand wheel; *49*, spindle.

The dimensions with reference to Fig. 186 are given in Table XXIX., the capacities and size of connections in Table XXX.

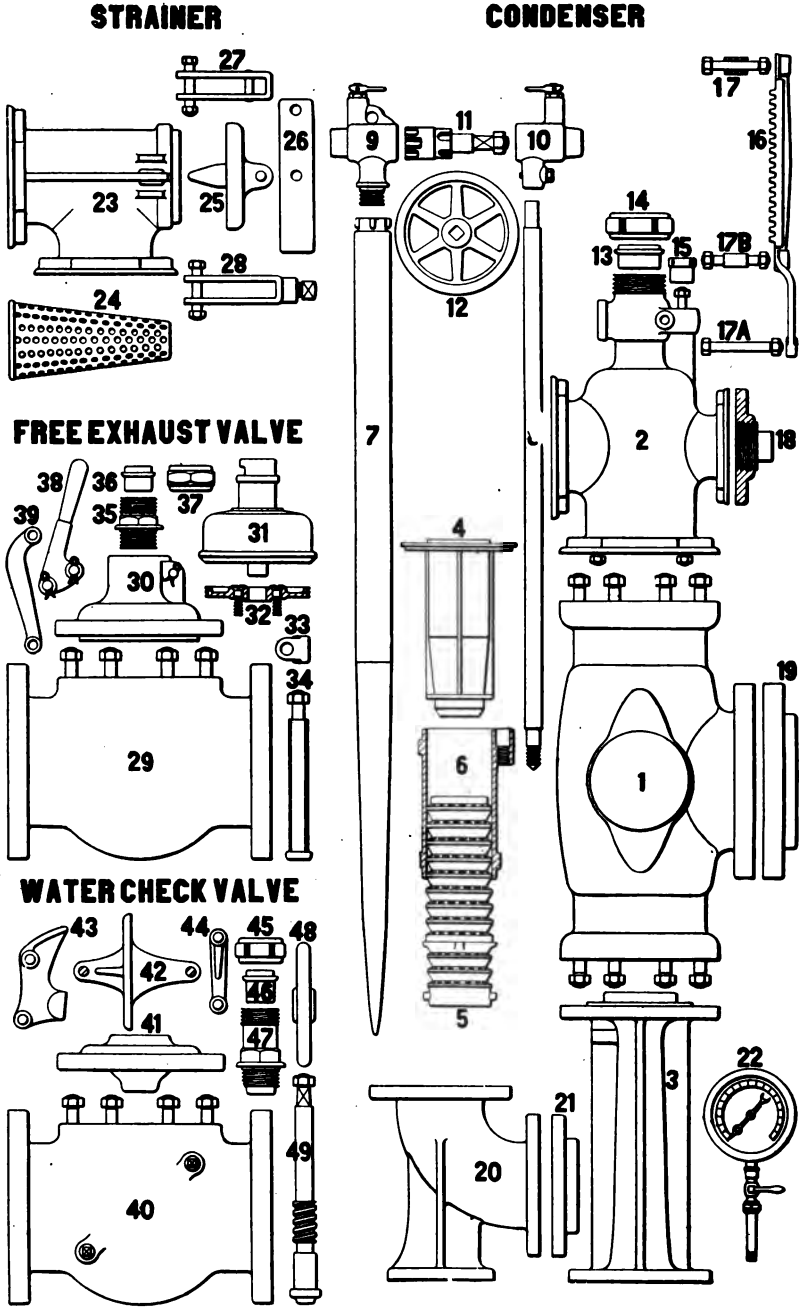


FIG. 187. PARTS OF INDUCTION CONDENSER.

TABLE XXIX.

Condenser.						Valves and Fittings.					
Size in Inches.	*D*	*E*	*F*	*G*	*I*	Center to Face.	Diam. of Flange.	Diam. of Bolt Cir.	No. of Bolts.	Diam. of Bolt.	Thick. of Flange.
1½	2	2¾	7	7½	2½	3⅜	5	4	4	½	½
2	2½	3¼	7½	8¼	2¾	3¾	6	4¾	4	½	9/16
2½	2¾	3¾	8	9½	3	4¼	7	5½	4	½	⅝
3	3¼	4⅛	8¾	12½	3½	4¾	7½	6	4	½	11/16
3½	3¾	4½	10¼	15	3¾	5¼	8½	7	4	½	¾
4	4	5	11½	17½	4	5¾	9	7½	4	⅝	13/16
4½						6	9¼	7¾	8	⅝	13/16
5	4½	5½	13¾	21½	4½	6½	10	8½	8	⅝	⅞
6	4¾	6½	16⅛	25¾	5	7	11	9½	8	⅝	⅞
7	5	7¼	18⅝	30½	5½	8	12½	10¾	8	⅝	15/16
8	5¼	8	21	35½	6	8½	13½	11¾	8	⅝	1
9	5¾	9	24	40⅞	7	9½	15	13¼	12	⅝	1
10	6½	10	27	46¼	7¾	10½	16	14¼	12	¾	1 1/16
12	7	11	31	53	8½	12	19	17	12	¾	1⅛
14	7¾	12	36	61¾	9	14	21	18¾	12	⅞	1 3/16
16	8¼	14	42	70	10	16	23½	21¼	16	⅞	1¼
18	10	15	45½	78⅝	11½	18	25	22¾	16	1	1 5/16
20	11¼	18	54	88	14	20	27½	25	20	1	1⅜

TABLE XXX.

Size of Condenser. Diameter of Exhaust.	Water Consumption per Minute. Maximum.		Diameter of Pipes.			Approximate Horse-power for Evaporation per Horse-power per Hour.		
	Gals.	Cu. Ft.	Water Supply and Discharge.	Steam.	Overflow.	20 Lbs.	30 Lbs.	40 Lbs.
1½	15	2	1	¼	½	15	10	7 5
2	26	3.5	1¼	½	¾	26	17	13
2½	37	5	1½	½	1	38	25	19
3	52	7	2	¾	1¼	52	35	26
3½	75	10	2½	¾	1½	75	50	38
4	112	15	3	1	1½	112	75	56
5	165	22	3½	1¼	2	165	110	82
6	240	32	4	1½	2½	240	160	120
7	330	44	4½	1½	3	330	220	165
8	450	60	5	2	3½	450	300	225
9	600	80	6	2	4	600	400	300
10	750	100	7	2½	4½	750	500	375
12	1,050	140	8	2½	5	1,050	700	525
14	1,425	190	9	3	6	1,425	950	712
16	1,800	240	10	3½	7	1,800	1,200	900
18	2,400	320	12	4	8	2,400	1,600	1,200
20	3,000	400	14	5	9	3,000	2,000	1,500

The average amount of water required by a condenser is twenty-five times that evaporated for use of the engine to which it is attached. If, therefore, this is known, the size of condenser is selected from table of capacities, in which the maximum water consumption is given, and it should correspond to the maximum work of engine.

If the maximum steam consumption is not known, it can be readily calculated in the following manner: Take the displacement of the piston, at initial or terminal pressure, and divide the same by the corresponding specific volume.

Example.—Engine 18 × 48, 50 revolutions; initial pressure 70 lbs. following ¼ stroke; area 18 in. = 1.77 sq. ft. Volume 1.77 × 4 × ¼ × 100 = 177 cub. ft., spec. vol. of 70 lbs. = 315, = $\frac{177}{315}$ = 0.562 cub. ft. evaporated for use of engine; this multiplied by 25 = 14.05 cub. ft. per minute required by condenser.

Example.—Engine 18 × 48, 50 revolutions, terminal pressure in cylinder 4.7 lbs., area 18 in. = 1.77 sq. ft. Volume 1.77 × 4 × 100 = 708 cub. ft., spec. vol. of 4.7 lbs. = 1260, = $\frac{708}{1260}$ = 0.562 cub. ft. evaporated for use of engine; this multiplied by 25 = 14.05 cub. ft. water required per minute by condenser.

Comparing the above results with Table XXX. we get a 4-inch condenser having a maximum of 15 cub. ft.

Long underground suction pipes should, if possible, be avoided; otherwise breaks and leaks cannot readily be located and corrected. It is advisable to have a well at a convenient point near the condenser, and water flowing into it by gravity. The condenser thus takes water from the well, and suction pipe is short and exposed.

As the condenser needs both a supply and discharge pipe, the well can have a partition, while both pipes lie in one trench from well to river. Fig. 188 shows such an arrangement.

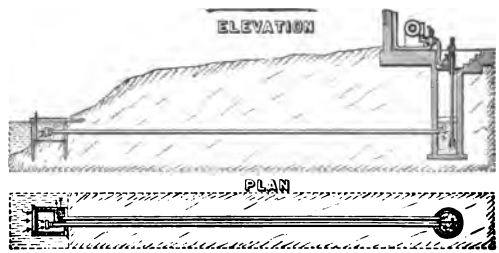


FIG. 188. ARRANGEMENT OF CONDENSER.

The discharge pipe should always be carried down to the lowest level, and in no case be led upwards above the foot elbow. A trap at end can be formed by an upward turn or fitting, which need not be deeper than the diameter of the pipe.

The diameter of water supply and discharge pipes should be as

per Table XXX., for a distance not exceeding 50 ft. If the distance is more than 50 ft. and up to 100 ft., the diameter should be 20 per cent. larger; if more than 100 ft. and up to 200 ft., 30 per cent.; if more than 200 ft. and up to 300 ft., 40 per cent.; and if more than 300 ft. and up to 400 ft., 50 per cent.

The exhaust pipe, water supply and discharge, as also all fittings, joints, stuffing boxes and pet cocks, must be perfectly air tight.

This condition is important; cause for failure to obtain a good vacuum will generally be found in air leaks.

The free exhaust valve should also be examined for air leaks after it has been hot a few times, and should be reground if necessary.

It is desirable to attach an air valve about one sixth diameter of exhaust somewhere on the exhaust pipe. Air admitted here destroys the vacuum and engine stops promptly.

Traps in heater or exhaust pipe should be drained into the condenser, and drain pipe fitted with a check valve.

FIG. 189. HORIZONTAL WATER CHECK VALVE.

FIG. 190. AUTOMATIC FREE EXHAUST VALVE.

Valves.—1. Horizontal water-check valve, Fig. 189. This valve is used in connection with the exhaust pipe from engine to condenser and its purpose is to prevent a back flow of water to engine.

The spindle is for the purpose of a stop to limit the stroke or to close valve entirely when condenser is not in operation.

The center of gravity is slightly near the supporting bar, causing valve to close.

This valve is an important safety-device for all condensing engines.

2. Automatic free exhaust valve, Fig. 190. This valve closes automatically when vacuum is on condenser, and opens automatically when vacuum is destroyed. The noiseless piston prevents hammering. By turning the hand lever to the right, the valve is locked open.

SIXTH PART.

THEORY.

Mechanical Theory of the Steam-Jet Pump.

The theory of the flow of steam through nozzles has been made clear by experiments carried out in connection with steam turbines. It is now well known that an increase of velocity will be imparted to steam passing through an orifice into a space of lower pressure, which depends upon the difference of the pressures. The increase will go on for a certain period, will reach a maximum and will then remain unchanged, no matter how much the difference of pressures is increased. This limit is reached when the pressure outside is about half as high as in the pressure space or, if we express it exactly, if the ratio of the pressures is

$$\frac{p_1}{p} = \left(\frac{2}{n+1}\right)^{\frac{n}{n-1}}$$

For dry saturated steam—if no heat is transmitted to or abstracted from it—$n = k = 1.135$ and hence the ratio $p_1/p = 0.5774$, which is about one half. This phenomenon is explained by the fact that the pressure in the plane of the escape opening is equal to the pressure outside, only, if $p_1/p \leqq 0.5774$, but smaller for $p_1/p < 0.5774$. Hence, if the outside pressure is lower than $0.5774\ p$, the escaping steam jet has or retains a certain "interior" pressure, whereby it is expanded.

In order to impart to the steam jet a higher velocity as the one corresponding to the above-mentioned critical pressure, a conically enlarging tube, the Laval nozzle, has to be connected to the orifice. If we assume the Laval nozzle to be composed of a number of small cylindrical pipes of increasing diameter, we can say that the steam, when leaving the first pipe, has still some interior pressure and therefore fills the second pipe. When leaving the latter it still retains a certain pressure and fills the third, etc. This process, going on continuously, takes place also in the Laval nozzle, the energy liberated by the expansion of the steam being imparted to the steam as kinetic energy; this explains the immense velocities obtained in steam turbines.

If in a conical nozzle the proportion of the smallest cross-sectional area to the area of the orifice is such that the steam passing through expands from the critical pressure of the smallest area, to a pressure —at the orifice—equal to the outside pressure, then it will leave the orifice in parallel jets.

If the area of the orifice is larger, as would correspond to the expansion, the steam will have at the orifice a lower pressure as in the outside space and the excess of kinetic energy contained in the steam jet, will, by its impact to the outside steam of higher pressure, be retransformed into heat, a phenomenon which is accompanied by the arising of "pressure waves."

If the area of the orifice is too small so that the tension at the orifice is higher than the counter-pressure, the formation of pressure waves will also take place. Hence the nozzle effects an expansion, which depends upon the proportion of the smallest to the largest area but is independent of the counter-pressure.

As in injectors the highest possible velocity is desirable, conical nozzles are used. As an injector has to work at various steam pressures a regulating spindle is provided in order to obtain, in every case, the required proportion of the smallest to the widest area.

The kinetic energy of the steam is, in the mixing nozzle, transmitted to the water to be moved (impact). Assuming that both substances are perfectly non-elastic and that the impact is straight and central, we get the common velocity after the impact.

$$v = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2}$$

In this equation m_1 is the mass of steam per second, m_2 the mass of water per second, v_1 the velocity of the steam, v_2 the velocity of the water. In practice, however, this process will not take place at such regularity as is supposed in the equations and the losses of velocity will be considerably higher, as with a central non-elastic impact. The water and steam will be set whirling in the mixing nozzle. If, in consideration of the losses caused thereby, we introduce a factor ϕ, considering also that in the above equation the acceleration of the earth is contained in the mass, we arrive at the equation

$$v = \phi \frac{G_1 v_1 + G_2 v_2}{G_1 + G_2}$$

wherein G_1 stands for the weight of steam per second and G_2 for the weight of water per second.

In order to determine the dimensions of an injector, the quantity ϕ has to be calculated. Then the orifice of the mixing nozzle would be definitely fixed for a certain quantity of water to be moved and for a certain ratio of water to steam. All the other dimensions can be calculated from the area of the orifice.

If f is the area of the orifice, t the time, Q the weight of steam plus weight of water in time t, the relation between these quantities can be expressed by the equation $Q = ftv$.

However, if we apply this relation to practical results, we arrive at impossible figures, because the density of the jet is not equal to 1, as is silently implied in the equation. Hence we have to transform the latter into

$$Q = \gamma v f t$$

wherein γ stands for the specific gravity of the jet.

As Q, f, t can be determined by direct observation, v and J remain the two unknown values of the equation. These were determined by the German engineer, Ph. Michel.

At constant temperature and lift the velocity of the jet is necessarily dependent only upon the steam pressure, the position of the regulating spindle and the ratio of the weight of steam to the weight of water. The correctness of this assumption is directly evident, as the jet jumps freely from the mixing nozzle into the pressure nozzle, the two nozzles being absolutely independent of each other. Michel has proved this theory by a series of experiments, in which at a constant boiler pressure of 6 pounds and a constant position of the regulating spindle, a counter-pressure of 2, 6 and 8.75 atomspheres was provided. In equal times equal quantities were moved.

The results of Michel's experiments are:

1. The average specific gravity of the "liquid" leaving the mixing nozzle is $\gamma_1 = 0.25$ and $\gamma_2 = 0.48$ respectively. At constant pressure it decreases with the increased opening of the regulating spindle and *vice versa*.

2. The factor determining the "whirling" losses is in average $\phi_1 = 0.75$ and $\phi_2 = 0.66$ respectively. This factor gets smaller, if the regulating spindle is wider opened.

3. The maximum pressure in the feed line increases with the open-

ing of the regulating spindle. Simultaneously the quantity of water moved by one pound of steam is decreased.

4. With increasing height of lift the quantity of water moved by one pound of steam is also decreased.

Calorimetric Investigation of the Steam-Jet Pump.[1]

Let Fig. 191 schematically represent our apparatus from whose mode of action the occurrences in the injector may be derived.

A represents a cylinder which contains a piston and G_1 pounds of

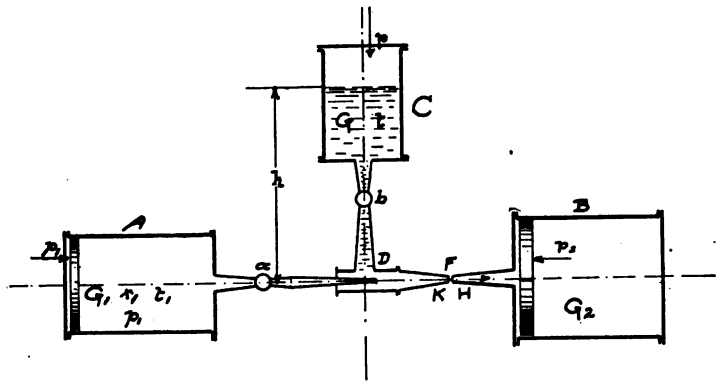


Fig. 191.

steam and water of the pressure p_1 and of the corresponding temperature t_1, the steam quality being x_1.

The cylinder is provided with a conical discharge pipe, whose discharge orifice lies in the interior of the casing D, which is provided with a large pipe K, that discharges at F into the open air.

Casing D is connected by a vertical pipe with an open vessel C which is under atmospheric pressure p and contains cold water of the temperature t. Let us at first suppose that both spaces A and C are shut off by the cocks a and b. If now both cocks are opened, steam will flow through the nozzle F, but will immediately be condensed by the cold water coming from vessel C. Hence the jet passing through the outer orifice F consists of a mixture of cold water and condensed steam.

The pressure p_1 in cylinder A can be kept at a constant height during the outflow, if the piston in the cylinder is supposed to be pushed forward with the constant pressure p_1. Let us also assume

[1] See Zeuner, "Technical Thermodynamics," translated by J. F. Klein.

that the level in vessel C is always kept in the same position by running water so that, during the entire process, it be at the height h above the center of pipe K, and, furthermore, so, that the flow of water into the casing D and the flow toward the mixing pipe also take place at constant pressure.

If now the jet, discharging horizontally through the orifice F is caught by a second pipe H and is guided by the latter to a second cylinder B, the transferred fluid, in order to find room, must push back a piston and overcome a constant back pressure p_2.

Let us now assume that the cylinder B and the receiving tube H are removed, and that the water jet flows directly into the open air at a velocity w_0 and a temperature t_2.

Before the two cocks, a and b, were opened the heat contents of the wet steam in cylinder A were $G_1\ (q_1 + x_1\rho_1)$, and Gq was the heat content of the cold water in vessel C; hence we have for the combined heat contents J_1 of both spaces,

$$J_1 = G_1(q_1 + x_1\rho_1) + Gq \qquad (1)$$

If the cocks are now opened and, to simplify matters, the weights G_1 and G are referred to the period of a second, then $G_1 + G$ pounds of water will discharge through the orifice F in this time, and, since the temperature of the mixture is t_2 and its velocity w_0, the heat contents of the whole mass will be

$$J_2 = (G + G_1)\left(q_2 + A\frac{w_0^2}{2g}\right) \qquad (2)$$

where $A \cdot w_0^2/2g$ represents the kinetic energy of the unit of weight of liquid, expressed in heat units.

The heat contents J_1 at the beginning, are by no means identical with the value J_2 at the end of the process as work is absorbed and delivered by the mass during the occurrence.

In cylinder A the piston is moved at the constant pressure p_1 through the space $G_1(x_1u_1 + \sigma)$; the absorbed work L_1, expressed in heat units, therefore amounts to

$$AL_1 = AG_1p_1(x_1u_1 + \sigma) \qquad (3)$$

In the vessel C the surface of the water is under the atmospheric pressure p and moves through the space $G\sigma$; to this the work Gh of the force of gravity is also to be added; hence the amount of the

absorbed work L_2 expressed in heat units, sums up to

$$AL_2 = AG(p\sigma + h) \tag{4}$$

Finally the weight of liquid $(G_1 + G)$ flowing through the orifice F has the volume $(G_1 + G)\sigma$ and must overcome the constant atmospheric pressure p during the discharge. Hence the work L_3 in heat units amounts to

$$AL_3 = A(G_1 + G)p\sigma \tag{5}$$

As now evidently the heat contents J_2 at the end are equal to the heat contents at the beginning, when increased by the heat equivalents of the absorbed work, and diminished by the heat equivalents of the delivered work, it follows that

$$J_2 = J_1 + AL_1 + AL_2 - AL_3$$

or, if we consider the relation $\rho_1 + Ap_1u_1 = r_1$,

$$(G + G_1)\left(q_2 + A\frac{w_0^2}{2g}\right) = G_1[q_1 + x_1r_1 + A(p_1 - p)] + G(q + Ah) \tag{6}$$

This is the first fundamental equation obtained in this investigation. We will now discuss under I a utilization of this equation and will continue our investigation on the injector under II.

I. Suppose the jet flowing through F into the open air is collected in a measuring tank in which, at the start, G_2 pounds of water of the temperature t_3 are contained; at the end the tank contains the weight $(G_1 + G_2 + G)$ of liquid. Let the temperature be t_4, then, if the heat contents at the end are J_4, we have

$$J_4 = (G_1 + G_2 + G)q_4$$

On the other hand we have before the mixture

$$J_3 = G_2q_3 + (G_1 + G)\left(q_2 + A\frac{w_0^2}{2g}\right)$$

Now, since no work was consumed nor produced during the mixture, we have $J_3 = J_4$, or, according to the preceding equations,

$$(G + G_1)\left(q_2 + A\frac{w_0^2}{2g}\right) = (G + G_1 + G_2)q_4 - G_2q_3 \tag{7}$$

which is the second fundamental equation for the present case. If we combine (6) and (7), we get

$$G_1[q_1 - q_4 + x_1 r_1 + A\sigma(p_1 - p)] = G(q_4 - q - Ah) + G_2(q_4 - q_3) \quad (8)$$

All the quantities of this equation, with the exception of the steam quality x_1, can be found by observation.

If the injector is directly connected to a boiler, we are enabled to ascertain whether the steam, flowing from the boiler to the injector, is dry or wet, and in the latter case we can determine x_1.

If the quantities G and G_1 are taken per second, and if F_0 is the cross-section of the orifice of efflux in pipe K, in square feet, there flows from the formula

$$F_0 w_0 = (G + G_0)\sigma \quad (9)$$

the efflux velocity w_0, and from this the kinetic energy measured in heat units

$$A\frac{w_0^2}{2g} = \frac{A}{2g}\left(\frac{(G + G_1)\sigma}{F_0}\right)^2 \quad (10)$$

Furthermore we find from equation (7) the heat q_2 of the liquid and the corresponding temperature t_2 of the water jet in the orifice F_0.

The utilization of equation (9) is somewhat uncertain; the water jet issuing from nozzle F has a milk-white appearance and seems to be loose and swollen, so that the specific volume σ is probably greater than ordinary water. This point was discussed in our consideration of the mechanical theory of the injector.

II. Let us now assume, in addition, that the jet flowing from orifice F is caught by the receiving tube H and led to cylinder B, where the mass pushes back the piston, overcoming the constant back pressure p_2.

At the end, after the expansion, let the temperature be t_2 and then the heat contents will be $J_2' = (G + G_1)q_2'$. The initial contents J_2 in the orifice F are determined by equation (2). The work L, performed in cylinder B, is

$$L = (G + G_1)(p_2 - p)\sigma,$$

and there follows from equation

$$J_2 = J_2' + AL,$$

and with the help of the given expressions,

$$q_2 + A\frac{w_0^2}{2g} = q_2' + A(p_2 - p)\sigma \qquad (11)$$

If we substitute this value in equation (6) we get

$$G[q_2' - q + A\sigma(p_2 - p) - Ah] = G_1[q_1 - q_2' + x_1 r_1 + A\sigma(p_1 - p_2)] \qquad (12)$$

If we consider the injector as a feeding apparatus and accordingly replace cylinder A and B by the boiler, then $p_2 = p_1$, and equation (12) is transformed into

$$G[q_2' - q + A\sigma(p_1 - p) - Ah] = G_1(q_1 - q_2' + x_1 r_1) \qquad (12a)$$

If we now add $G(q_1 - q_2')$ to both members of this equation we get

$$G[q_1 - q + A\sigma(p_1 - p) - Ah] = (G_1 + G)(q_1 - q_2') + G_1 x_1 r_1 \qquad (13)$$

This equation represents the principal result of the calorimetric investigation of the steam-jet pump.

The right member of this equation represents the heat quantity required for the operation of the injector. For, G_1 is the weight of a quantity of steam and water, which in a given time, say one second, passes from the boiler to the injector; it returns to the boiler together with the feed-water quantity G and has, after expansion, the temperature t_2'.

Now, the weight $(G_1 + G)$ must be raised from temperature t_2' to the boiler temperature t_1, which requires the heat quantity $(G_1 + G)(q_1 - q_2')$, and then the consumed steam quantity $G_1 x_1$ must again be evaporated under constant pressure, at the consumption of a heat quantity $G_1 x_1 r_1$; the heat quantity required for the operation of the injector is, in fact, as mentioned above

$$Q = (G_1 + G)(q_1 - q_2') + G_1 x_1 r_1$$

Then we have according to equation (13)

$$Q = G[q_1 - q + A\sigma(p_1 - p) + Ah] \qquad (14)$$

when the sign of h is changed and it is assumed that the feed water is not forced on the injector from the pressure head h, but has to

be sucked up the height h through the injector, as is ordinarily the case.

The preceding equation shows that the heat required for feeding with the injector is entirely independent of the quantity and constitution of the steam (of G_1 and x_1) which is necessarily used in its operation; it is also independent of the temperature of the jet in the orifice F and of the temperature t_2 at which the water enters the boiler, and is, furthermore, independent of the dimensions of the injector, provided it works at all and does not fail.

The two terms $A\sigma(p_1 - p)$ and Ah are in practice usually so small that they may be neglected; the height of suction h and the pressure p have, accordingly, very little influence on the heat quantity Q; it therefore does not matter whether the pressure p is identical with the external pressure or identical with the pressure in the mixing chamber.

These formulas give no clue as to the dimensions to be given to an injector; however, for the starting and setting into action, the suction head h and the temperature t of the feed water will be of marked influence.

The comparison of the injector with the ordinary feed pump is of technical importance.

Let A (Fig. 192) be the cylinder of a feed pump, F the cross-section of the piston, S the piston stroke; let the pump draw water from the open vessel B through the height h. The cylinder is supposed to be open on the right-hand side, regarded as single acting, and the atmospheric pressure p will prevail to the right of the piston; to the left of the piston the pressure will be $(p - h\gamma)$, where γ represents the specific gravity of the water. Accordingly the difference of the two temperatures is $h\gamma$, the piston force during suction $Fh\gamma$, hence the work L'

$$L' = Fh\gamma s$$

During the return of the piston the water is forced against the back pressure p_1 into the boiler, and the work L'' of this forcing action is

$$L'' = Fs\ (p_1 - p)$$

Both works taken together give the entire pump work L (neglecting frictional and hydraulic resistances), which then amounts to

$$L = Fs\gamma\left[\frac{p_1 - p}{\gamma} + h\right].$$

Let $Fs\gamma = G$ be the weight of the feed water, and, as $\gamma\sigma = 1$, we have for the work of the pump

$$L = G[(p_1 - p)\sigma + h] \qquad (15)$$

In the boiler the feed water must be heated from t to t_1, requiring a heat quantity Q', which is determined by

$$Q' = G(q_1 - q) \qquad (16)$$

but in the present case the heat quantity corresponding to the pump work L is not, say AL, but somewhat greater, even if the pump is

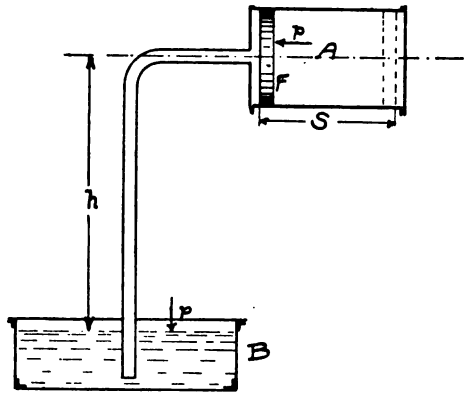


FIG. 192.

driven by a theoretically perfect engine. If we substitute the heat quantity ϕAL consumed in performing the work, where $\phi > 1$, there follows for the quantity of heat Q, which is absorbed by feeding with the feed pump

$$Q = G(q_1 - q) + \phi A[(p_1 - p)\sigma + h]$$

while, according to equation (14)the amount for the injector was found

$$Q = G(q_1 - q) + A[(p_1 - p)\sigma + h]$$

Accordingly the injector, as a feeding apparatus, is superior to the feed pump, being, in fact, from the theoretical standpoint, the most perfect apparatus for boiler feeding. As a water-raising apparatus for other purposes than boiler feeding it is less perfect, especially in cases where it is not desired or not necessary to heat the liquid to be lifted.

From all the above formulas approximate formulas can be derived, by leaving out the terms containing the factor A.

In this case equation (6) gives

$$(G + G_1)q_2 = G_1(q_1 + x_1r_1) + Gq$$

or if we assume dry saturated steam, designating the total heat $q_1 + r_1$ by λ, and finally, for the comparatively low temperatures t_2 and t, substitute the temperatures themselves, we get

$$t_2 = \frac{G_1\lambda_1 + Gt}{G_1 + G} \qquad (6a)$$

Accordingly we determine, approximately, the temperature t_2 of the jet at its entrance into the receiving tube H.

Neglecting as before, there follows from equation (11) $q_2' = q_2$ or

$$t_2' = t_2 \qquad (11a)$$

according to which, the temperature t_2' of the jet, after expansion, can be assumed as nearly equal to its temperature t_2 at the entrance into the receiving tube and probably in most cases can, with sufficient accuracy, be taken as of equal value.

Equation (6a) has been used considerably, but it was generally overlooked that it is only approximately correct.

If the temperatures t_1, t and t_2 were known, there would follow from equation (6a)

$$\frac{G}{G_1} = \frac{\lambda_0 - t_0}{t_0 - t} \qquad (6b)$$

and this would determine the weight of water G which is sucked in by the steam weight G_1. In choosing t_2 this formula would give the minimum quantity of water G necessary to effect complete condensation.

Theory of the Jet Condenser.

In Fig. 193 A represents the cylinder of a steam engine; suppose the piston be at the upper end of the stroke and the cylinder to contain G_1 pounds of steam of the pressure p_1 and of the quality x_1.

C represents the condenser containing G_2 pounds of steam and water, under a pressure p_2, the steam quality being x_2.

A pipe, opening into the side of the condenser, ends in a spray; the pipe is connected with vessel D, which contains G pounds of cold water of a temperature t, under the atmospheric pressure p_0.

The lower part of the condenser is connected by a pipe with a pump cylinder B.

Assuming now the four spaces to be shut off and separated from each other by the cocks a, b and c, the heat contents of the mass of steam and water in cylinder A are determined by $G_1(q_1 + x_1\rho_1)$,[2]

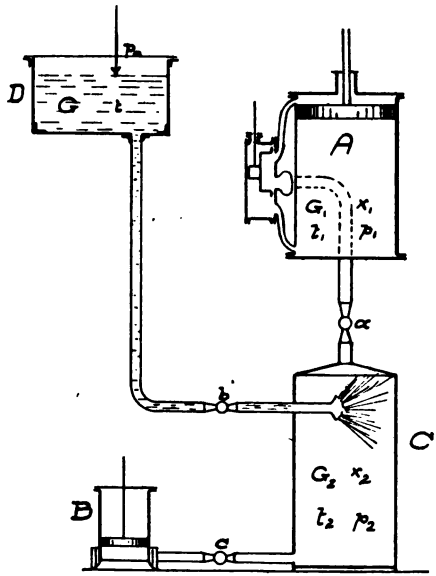


FIG. 193.

the heat of the mass in the condenser by $G_2(q_2 + x_2\rho_2)$, and the heat in the jet water in vessel D is determined by Gq. Accordingly the total heat contents J_1, in the three spaces mentioned, are

$$J_1 = G_1(q_1 + x_1\rho_1) + G_2(q_2 + x_2\rho_2) + Gq \qquad (1)$$

If now the three cocks are opened, the piston will move forward in the cylinder and push the mixture of G_1 pounds of steam and liquid into the condenser, overcoming thereby the constant pressure p_2. The jet water G passes under atmospheric pressure p_0 from the vessel D through the spray into the condenser, and finally the portion of the air and hot water pump B draws in, under pressure p_2, not only the jet water G, but also the weight G_1 of steam and liquid in the form of water.

At the end of this process the whole mass is united in the con-

[2] Zeuner, "Technical Thermodynamics" (ρ = inner latent heat).

denser and in the pump cylinder, and at this moment the total heat contents in the two spaces combined are

$$J_2 = G_2(q_2 + x_2\rho_2) + (G_1 + G)q_2 \qquad (2)$$

As we assume the engine to be running normally, the term which represents the heat contents of the mass in the condenser must have the same value at the end as in the beginning.

Moreover the mass in the steam cylinder has taken up the work L_1 and the jet water in the vessel D has absorbed the work L_2, and these quantities of work, expressed in heat, amount to

$$AL_1 = AG_1(x_1u_1 + \sigma)p_2 \qquad (3)$$

$$AL_2 = AG\sigma p_0 \qquad (4)$$

Finally there has been given off in the pump cylinder a quantity of work L_3 which, measured in units of heat, amounts to

$$AL_3 = A(G + G_1)\sigma p_2 \qquad (5)$$

Evidently the heat contents J_2, at the end, are equal to the heat contents J_1 at the beginning, increased by the algebraic sum of the quantities of work received, expressed in unit of heat, and therefore amount to

$$J_2 = J_1 + AL_1 + AL_2 - AL_3.$$

If we now make use of the preceding equations, we get for the fundamental equation of the jet condenser,

$$\frac{G}{G_1} = \frac{q_1 - q_2 + x_1(\rho_1 + Ap_2u_1)}{q_2 - q_1 - A\sigma(p_0 - p_2)} \qquad (6)$$

from which the jet water G can be calculated. In order to transform this equation for practical use, *i. e.*, for obtaining a simple, approximate formula, the very small term $A\sigma(p_0 - p_2)$ in the denominator can be neglected; moreover we can take $x_1 = 1$ and therefore assume dry steam in the steam cylinder and also *one atmosphere* for the final pressure of expansion; if, besides, the condenser pressure is $p_2 = 0.1$ atm., we must assume $q_1 = 100.50$, $\rho_1 = 496.30$, $Ap_2u_1 = p_2/p_1 \cdot Ap_1u_1 = 4.02$, [$q_1 = 180.90$, $\rho_1 = 893.34$, $Ap_2u_1 = 7{,}236$], and therefore

$$\frac{G}{G_1} = \frac{600 - q_2}{q_2 - q}$$

$$\left[\frac{G}{G_1} = \frac{1080 - q_2}{q_2 - q}\right]$$

or, substituting the temperature for the heat of the liquid, we get

$$\frac{G}{G_1} = \frac{600 - t_2}{t_2 - t} \qquad (6a)$$

$$\left[\frac{G}{G_1} = \frac{1080 - (t_2 - 32)}{t_2 - t} = \frac{1112 - t_2}{t_2 - t}\right]$$

A large volume of air enters into the jet condensers, and is absorbed and carried along by the jet water. Most of it is given off in the condenser, where a higher temperature and lower pressure prevails than outside; but our condenser theory is only slightly interfered with thereby.

In order to take account of this fact, it is only necessary to build the air and hot water pump in more liberal dimensions. Ordinarily it is estimated that the volume of air, which is simultaneously withdrawn by the pump with the water from the condenser amounts to 11/14 of the volume $G\sigma$ of the jet water.

The Flow of Steam Through Orifices.

It has been known for a long time that the flow of steam through orifices is dependent only (for the one orifice) on the initial pressure so long as the subsequent pressure, that against which the flowing steam expands, is never greater than about 0.58 of the initial pressure. A large number of investigations, also, have been made toward determining the quantity of flow under this relation of pressures, but, in general, these have all been based on the weight of steam which is condensed in a surface condenser. A. Rateau has undertaken a series of experiments on the subject, according to a method which he considers gives very great precision. From 140 sets of observations he deduced a formula for the amount of flow, which formula, he says, furnishes the consumption very exactly.

The method is to condense the steam in a stream of water with the use of an ejector condenser and measure the total yield of water together with the initial and final temperatures of the stream—the amount of water being determined by discharge through a previously calibrated water orifice and the whole arrangement permitting the experimenter to make all readings at the same moment, as soon

as constant conditions are obtained, whereas with the more common method referred to, the weighing of water from the surface condenser is required after a sufficiently long period of operation. Each experiment does not last more than one or two minutes, which, Rateau says, has at least the advantage over the other method, that the period is not long enough for any material variation to take place in initial steam pressure.

The supply of steam is received through a pipe 1.97 inches in diameter and passes through the orifice into a pipe of 4.72 inches diameter. Precautions were taken to separate water from the steam, so that the quantity of water never exceeded three thousandths. Valves were arranged to regulate the pressure both in front of and behind the orifice, and a range of pressures, from 1.4 to 170 pounds per square inch, were obtained. The three converging nozzles had diameters at the narrowest parts, as follows: 0.41, 0.59 and 0.95 inch. The formula for the total flow is as follows:

$$W = 3.6P(16.3 - 0.96 \log P)$$

where W is the number of pounds discharged per hour per square inch of area of the orifice and P is the initial pressure in pounds per square inch, the logarithm being that referring to the common base 10.

APPENDIX.

REMARKS ON THE NATURE OF MACHINES.

I.

According to Noah Webster a machine is in general any combination of bodies so connected that their relative motions are constrained, and by means of which force and motion may be transmitted and modified, as a screw and its nut, or a lever arranged to turn about a fulcrum, or a pulley about its pivot, etc. More especially machines are constructions more or less complex, consisting of a combination of moving parts, or simple mechanical elements, as levers, cams, etc., with their supports and connecting framework, calculated to constitute a prime mover, or to receive force and motion from a prime mover or from another machine, and transmit, modify and apply them to the production of some desired mechanical effect or work, as weaving by a loom, or the excitation of electricity by an electrical machine.

This is Webster's technical definition of the term machine. Regarding the common use of this word he says: The term machine is most commonly applied to such pieces of mechanism as are used in the industrial arts, for mechanically shaping, dressing and combining materials for various purposes, as in the manufacture of cloth, etc. Where the effect is chemical or other than mechanical, the contrivance is usually denominated an apparatus, not a machine, as a bleaching apparatus. Many large, powerful or specially important pieces are called engines, as steam engine, etc. Although there is no well-settled distinction between the terms engine and machine among practical men, there is a tendency to restrict the application of the former to contrivances in which the operating part is not distinct from the motor.

All this shows that the definition of the term machine is rather uncertain, as it is very difficult indeed to comprise such widely differing objects as a lever, a steam engine, a centrifugal pump, a dynamo and a steam-jet blower under the same definition. Hence we will now try to arrive at a satisfactory definition, and in order to attain

this end we will first consider a simple machine without moving parts, viz., a jet machine. We will then try to apply the result obtained to the more complicated machines; finally we will consider the relations of machines to matter and life.

The working of every jet machine is based upon the fact that a liquid or gaseous jet passes through another liquid or gas (under pressure, from a nozzle), causing a motion in the adjoining parts of the mass, so that a vacuum would be formed, if it would not be immediately annihilated by the motion of the particles of the respective substance. The jet draws and sucks in the surrounding mass, mixes with it and transmits to same a part of its own momentum, so that both escape together. If now the common velocity is reduced by a counter-pressure, a corresponding part of the momentum of the mixture is transformed into pressure, which serves to overcome the counter-pressure.

If a steam jet passes through a cooler liquid or if steam is sucked in by a cooler jet formed of a liquid, the steam is condensed in the mixing process and the suction will be the more intense, the more complete the condensation.

We see now that in the ordinary jet machine work is produced by using part of the velocity of the passing steam for the transportation of other substances and that, in other cases, the heat of the steam, liberated by condensation is so transformed that it serves for the transportation of other gaseous or liquid substances. In every one of these cases the energy content of the steam is changed. In each case a transformation of energy takes place in the steam. The jet-"machine" is nothing but the housing, in which certain transformations of energies occur, and the machine proper is the steam, *i. e.*, the matter working in the housing. If, by some meteorological reason, an immense jet of steam or hydrogen issues from the sun, this jet travelling at immense velocity also represents a machine with "drawing" and "sucking" action. But this jet is a machine without housing. In fact, the housings (for energy transformations) built by men, have no other purpose, from a physical point of view, but to effect a transformation as complete as possible, in the desired manner. We will now thoroughly discuss this important physical problem.

II.

It is well known that heat or heat-energy always flows from the warmer to the colder place, the same as electric energy flows from the places of higher tension to the places of lower tension. Temperature and tension are called the intensities of the respective energy and the above fact is formulated in the law that in the flow of the energies the intensities are decreased.

We know from the law of the conservation of energies that the energy of the world is constant, and that energy is never lost or annihilated. Accordingly with the decreasing intensity some other factor of the energy must increase, as otherwise some energy would be lost. To-day, indeed, every energy is conceived as a product of two factors, the intensity, which was already mentioned, and a second factor, called capacity. The capacity of the heat energy is called entropy, the capacity of the electric energy is called quantity of electricity. Hence temperature times entropy is heat energy, tension times quantity of electricity is electric energy. And the flow of energy, *i. e.*, the "happening," takes such a course that the intensities are decreased and the capacities increased.

The law of the conservation of energies has the most general validity, no matter whether the flow of one energy or the transformation of one energy into another is considered. In the latter case such quantities of energies, which can be transformed into each other are called equivalent.

The law of the conservation of energies only expresses the conservation of the product (intensity times capacity): the product of the factors of the energy equals the product of the factors after the change. By this law the product is fixed and determined, but nothing is said about the quantity of the factors.

If we transform a certain quantity of heat energy into electric energy, there is absolutely no relation between the intensity of the heat energy to be transformed and the intensity of the electric energy obtained by the transformation. In fact, the intensities of the various energies cannot be compared nor measured with each other. We cannot say, that a certain temperature corresponds to a certain electric tension. All this follows from the product character of the energy.

Hence it is in our power to fix, to determine or to predetermine —in the transformation of energies—the intensity of the energy to

be obtained by the transformation. The means to this end are called machines.

By a corresponding change of the machine we can change the intensity of the energy to be obtained. With a certain waterfall we can either drive a larger wheel at lower speed, or a smaller wheel at higher speed, *i. e.*, we can obtain the mechanical energy in the intensity desired. According to the construction of a dynamo we can transform the mechanical energy of one and the same steam or gas engine into electric energy of high or low tension. With the fixed working capacity of a pump we can either raise a larger quantity of water to a lower height, or a smaller quantity to a greater height. We can make the same observation with air-compressors, etc. The energy, the product is fixed; the determination of the factors is at our command.

An industrial machine, therefore, is an apparatus, which allows the transformation of one energy into another and the predetermination of the intensity of the energy to be obtained by the transformation. By connecting two machines in such a manner, that the energy produced by the first is retransformed by the second machine into the energy which was fed to the first machine, we can recover the "first" energy in any intensity desired. This is a way for increasing the intensities, as following examples will show:

The energy of a certain waterfall, *i. e.*, a fall of certain height (intensity) and certain quantity of water (capacity) is used for driving a water wheel, the latter being connected to a pump. Not considering the friction losses we can raise with this pump either the entire quantity of the falling water to its original height, or a correspondingly smaller quantity to a correspondingly greater height. The latter case shows an increase of intensity.

In the same way we can transform heat into electric energy of any desired tension, and the latter again into heat of any temperature. From these examples we see clearly that a machine is a means to increase the intensity.

While in the flow of a single energy the intensity is always decreased, we can observe that in the transformation of energies the intensity of the energy to be obtained depends upon the construction of the machine used.

We have so far discussed the machines built by man. We will now try to apply our results to the natural phenomena at large.

The earth receives from the sun radiant energy, which, by passing through the atmosphere of the earth is partly transformed into heat. As a transformer of radiant energy into heat the earth is a machine and the effect of the work of this machine are the geological and meteorological phenomena. Other kinds of machines are the plants, in which the radiating energy is transformed into chemical energy. By suitable transformation of the chemical energy contained in the plants we can produce any desired energy in any desired intensity.

The animals are machines for transforming the chemical energy of the plants into other forms. The higher we go in the evolutionary series the more efficient are the machines and the greater the number of energies transformed by them.

While in the suns the transformation of chemical, mechanical and heat energy into radiant energy plays such an important part, the nebulæ are apparently machines, in which radiant energy and heat of low intensity, by passing through the stages of chemical and mechanical energy, is transformed into radiant and heat energy of high intensity, whereby they become suns.

Hence every part of the world is a machine as regards the energies affecting it from all the rest of the universe. For the sun as steam engine the rest of the universe is the steam boiler. The planets are machines mainly as regards the energy obtained from their sun. The planets evolve—in the course of evolution—machines, the organisms, which transform the energies in more "refined" forms. We consider these organisms the more perfect, the more energies they transform and the higher the efficiency at which they work.

We now see that there are ways and means to decrease the capacities and to increase the intensities, these ways being based upon the fact that only the product of both is fixed, but not the factors. This causes the constantly variable change of the natural phenomena. If it were not possible to increase the intensities, *i. e.*, if the intensities of the various energies would have a certain ratio or relation to each other, then the universe, if it is eternal, would have necessarily died into absolute, motionless rest by reason of the constantly decreasing intensities. But as, according to the above explanation, the systems of suns, the suns, the planets, the nebulæ, etc., are, if their functions are considered, machines, just as the machines built by man, and as also all the organisms, we can understand the enternity of the natural phenomena. The eternal circle

of phenomena is made possible by the machine character of the components of the world, as thereby the intensities can be increased and the capacities decreased.

If we now try to investigate more closely the nature of a machine in general, we will find that every matter, be it organic, inorganic or organized is a machine, as in all of them a part of the affecting energies is transformed into other forms. Every matter and, according to our experience, matter only is a machine for the transformation of energies. Hence matter has in the universe the function of *the* transformer of energies. The law of the conservation of matter insures the eternity of the transformation of energies by the eternity and conservation of the transformer of energies.

It was stated above that the higher we go in the evolutionary series, the more varied become the functions of the machines, as the number of energies transformed by them is constantly increasing. The plant requires but a limited number of light rays; the lower animals react upon a small field of radiation only, compared with man. Sound waves which cause transformation of energies in man do not affect plants and low animals.

Compared to the animals in which through the differentiation of the senses a vast number of energies is transformed, the machine character of inorganic matter is much more simple and primitive. Inorganic matter reacts upon a small number of energies only, and the efficiency changes with the matter and energy under consideration. Certain energies are more or less transformed, while others pass practically unchanged through the same material. Window glass, for instance, allows a large portion of the spectrum to pass through unchanged, but acts as a machine in regard to certain ultra-rays, while it does not at all react upon electric energy. If heat acts upon a copper rod, a part of the heat will be transformed into volume-energy, the rod expands; electric energy, however, passes practically unchanged through copper, but is transformed into heat when acting upon other materials. Certain inorganic materials transform radiant energy, others heat into chemical energy. In the formation of sulphur flowers, zinc dust and gray tin, in which the surface is increased, we have a partial transformation of heat into surface-energy. Much less varied in their functions, as compared to inorganic matters, are the machines built by man, as they are only capable to transform *one* energy. The steam engine trans-

forms heat into mechanical energy, but cannot be used for the transformation of mechanical or radiant energy into electric or other energies.

Hence we can say: All matter, all materials are machines, in all of them a portion of the energies acting upon them is transformed into other forms. The smallest number of energies is transformed in inorganic matters, while in the organisms the number of energies transformed and also the efficiency increases with the progressing evolution.

This result also contains the principal difference between chemical and physical phenomena: In a physical phenomenon a transformation of energy takes place by means of matter; this is comparable to an engine, which is being started or in operation. A chemical phenomenon, however, means the production of a new machine from the parts of one or more old machines, or of two or more new machines from one old machine, and is therefore comparable to the construction of a new machine. Physics deals with the operation, chemistry with the construction of machines.

We will now consider the difference between living and lifeless matter.

We allow a source of heat to act upon a piece of iron. In this process not the entire quantity of heat transmitted to the iron, will pass through same, as a part of the heat is used for increasing the volume of the iron, until the latter has reached the volume corresponding to the higher temperature. From this moment on all the heat passes through unchanged. We can say that the iron is adapted to the "irritation" produced by the source of heat. Regarding the property of receiving heat from the outside and giving it off again, the iron behaves like living matter, through which also a flow of energy is passing, without changing its form and construction. In this respect the iron is a stationary formation, just as an organism. The same considerations can be made with all matters: they are all stationary formations as regards the energies of the rest of the world acting upon them.

From this standpoint the difference between lifeless and living matter is the fact, that through the latter a flow of chemical energies is passing, while through the former "matterless" energies are flowing. The process of assimilation in living matter corresponds to the transformation of non-chemical energies in lifeless matter.

In living matter every transformation of energies leaves a permanent impression, a lasting change. We are not what we have been an hour ago, though the difference in many cases is hardly noticeable. Lifeless matter also furnishes examples for this "permanent change." Spelter, which is brittle at ordinary temperature, becomes soft and tough if heated to about 120° centigrade and retains this property also after cooling. If we heat two pieces of steel to the same temperature and then cool the one quickly, the other slowly, the way of the cooling will be permanently impressed upon every piece. A photographic plate is permanently changed by radiant energy. Albumen heated to the temperature of coagulation remains insoluble. It is hardly necessary to go on enumerating more examples, as we always assume, in our daily work, without ever being disappointed, that the results of transformations of energies are practically permanent. I feel sure that I will find the result of the typewriter upon this sheet, if I will look at it to-morrow.

The law of the permanent effect is also correct for more delicate reactions. A steel beam of the Brooklyn bridge is not the same to-day, that it was yesterday. The permanent vibrations, the continuous transformation of mechanical energy into other forms have caused changes in the crystallization, etc., of the steel. In this case we have also a flow of energy, a transforming machine, a stationary state and an adaptation, which progresses until the adaptability—this property is specific for every matter—is exhausted.

We return again to the piece of iron, upon which heat energy is acting. The energy acts here like an irritation, and this affection is so changed by the iron, that the irritation ceases to be an irritation, which is effected by the expansion of the iron, *i. e.*, by the transformation of heat into volume-energy. When the force of resistance of the iron against the change is exhausted, then it is adapted to the irritation. In a similar way a photographic plate gets adapted to the energies for which it is a machine. Hence the adaptation and the permanent impression (memory) is not a characteristic of the living matter.

Another quality frequently ascribed exclusively to living matter is the vital self-conservation and the active resistance (egoism). However we find these same qualities, though less varied and naturally more primitive, in lifeless matter. The common spelter is

also egoistic, it resists its transformation into the "malleable" form, and a large quantity of heat energy must be expended to overcome this resistance. Iron resists any increase of temperature by "automatically" increasing its volume. This "resisting" is a fundamental quality of matter, as the period of resistance is identical with the period of energy-transformation. Without resistance there would be no transformation, as the latter comes only into effect by the resistance of matter and the pressure of the outside energies. A certain pressure is necessary to coin a gold-piece, just as a certain pressure of conditions is necessary to change our conduct or our face. The effect of a sudden, great accident is indeed very similar to the effect of a coin-press. Hardly has it happened and already we are adapted to it as if we knew it since many years.

Even the process of regeneration, which is now considerably exploited by the "vitalists" is found in lifeless matter: In cases, where through a change of the chemical equilibrium the concentration of the hydrogen ions is decreased, hydrogen ion is "reproduced." Hence also this difference is by no means qualitative, but only quantitative.

The growth of the organisms is identical with the crystallization of lifeless matter.

Adaptation, which from our standpoint is identical with memory, is the fundamental phenomenon of the lifeless and living world, from the simplest inorganic processes up to the most complicated mental processes, which in their highest form are conscious and intentional: Upon adaptation is based the imitating behavior of animals and man and the adaptation to certain impressions is the main factor in human education.

We now see that all differences between lifeless and living matter are only quantitative. Lifeless matter reacts upon a few forms of energy only; living matter upon a good many. Lifeless matter has a more limited adaptability as compared to living matter. However, through both a flow of energy is passing, which on its way is more or less transformed into other forms of energy.

Finally I want to say a few words about the function of energy. We have seen that in the reaction between matter and energy not only the latter but also the former is changed. Hence it is the function of energy to act as a transformer of matter.

We have therefore arrived at the result that the transformation

of energy and the transformation of matter is caused by the reaction between energy and matter. The "permanent effect" of the transformation of energy in matter is the origin of "memory," while "adaptation" is explained by the resistance of matter to the process of transformation. Memory and adaptation are the two main factors of evolution.

TABLES.

TABLE OF LOW PRESSURE STEAM.

Temperature in ° Fahr.	Latent Heat B.T.U. per Lb.	Total Heat from 32° Fahr. B.T.U. per Lb.	Pressure above Zero, in Lbs. per Square Inch.	Vacuum in Inches of Mercury.	Weight in Lbs. per Cubic Foot.	Volume in Cubic Feet per Pound.	Temperature in ° Fahr.	Latent Heat B.T.U. per Lb.	Total Heat from 32° Fahr. B.T.U. per Lb.	Pressure above Zero, in Lbs. per Square Inch.	Vacuum in Inches of Mercury.	Weight in Lbs. per Cubic Foot.	Volume in Cubic Feet per Pound.
60	1072.2	1100.2	.26	29.40	.0008	1220	110	1037.4	1115.5	1.26	27.34	.0038	263.2
61	1071.5	1100.5	.26	29.38	.0008	1176	111	1036.7	1115.8	1.30	27.27	.0039	256.4
62	1070.8	1100.8	.27	29.36	.0009	1136	112	1036.0	1116.1	1.34	27.19	.0040	250.0
63	1070.1	1101.2	.28	29.34	.0009	1099	113	1035.3	1116.4	1.38	27.11	.0041	243.9
64	1069.4	1101.5	.29	29.32	.0009	1064	114	1034.6	1116.7	1.42	27.03	.0042	237.5
65	1068.8	1101.8	.30	29.30	.0010	1031	115	1033.9	1117.0	1.46	26.94	.0043	231.0
66	1068.1	1102.1	.31	29.28	.0010	1000	116	1033.2	1117.3	1.50	26.86	.0044	224.7
67	1067.4	1102.4	.32	29.26	.0010	970.8	117	1032.5	1117.6	1.55	26.77	.0046	218.8
68	1066.7	1102.7	.33	29.23	.0011	934.6	118	1031.8	1117.9	1.59	26.68	.0047	212.8
69	1065.9	1103.0	.35	29.21	.0011	901.0	119	1031.1	1118.2	1.64	26.59	.0048	207.0
70	1065.3	1103.3	.36	29.19	.0011	869.5	120	1030.4	1118.5	1.68	26.50	.0050	201.6
71	1064.6	1103.6	.37	29.16	.0012	840.4	121	1029.7	1118.9	1.73	26.40	.0051	196.9
72	1063.9	1103.9	.38	29.14	.0012	813.0	122	1029.0	1119.1	1.78	26.30	.0052	192.0
73	1063.2	1104.2	.40	29.11	.0013	737.4	123	1028.2	1119.5	1.83	26.20	.0053	186.9
74	1062.5	1104.5	.41	29.08	.0013	763.4	124	1027.6	1119.8	1.88	26.09	.0055	182.7
75	1061.8	1104.8	.42	29.05	.0013	740.7	125	1026.9	1120.1	1.93	26.00	.0056	177.6
76	1061.1	1105.1	.44	29.02	.0014	719.4	126	1026.2	1120.4	1.98	25.88	.0058	173.0
77	1060.4	1105.4	.45	28.99	.0014	699.3	127	1025.5	1120.7	2.04	25.77	.0059	168.6
78	1059.7	1105.7	.47	28.96	.0015	675.6	128	1024.8	1121.0	2.10	25.65	.0061	164.5
79	1059.0	1106.0	.49	28.93	.0015	653.6	129	1024.1	1121.3	2.15	25.54	.0062	160.3
80	1058.3	1106.3	.50	28.90	.0016	632.9	130	1023.4	1121.6	2.21	25.42	.0064	156.3
81	1057.6	1106.6	.52	28.86	.0016	613.5	131	1022.7	1121.9	2.27	25.30	.0066	152.5
82	1056.9	1106.9	.53	28.83	.0017	595.2	132	1022.0	1122.2	2.33	25.17	.0067	148.6
83	1056.2	1107.3	.55	28.79	.0017	578.1	133	1021.3	1122.5	2.40	25.04	.0069	144.9
84	1055.5	1107.6	.57	28.76	.0018	561.8	134	1020.6	1122.8	2.46	24.91	.0071	141.4
85	1054.8	1107.9	.59	28.72	.0018	546.5	135	1019.9	1123.1	2.53	24.78	.0072	137.9
86	1054.1	1108.2	.61	28.68	.0019	529.1	136	1019.2	1123.4	2.59	24.64	.0074	134.6
87	1053.4	1108.5	.63	28.64	.0019	512.8	137	1018.5	1123.7	2.66	24.50	.0076	131.5
88	1052.7	1108.8	.65	28.60	.0020	497.6	138	1017.8	1124.0	2.73	24.36	.0078	128.2
89	1052.0	1109.1	.67	28.55	.0021	483.1	139	1017.1	1124.3	2.80	24.21	.0080	125.2
90	1051.3	1109.4	.69	28.51	.0021	469.5	140	1016.4	1124.6	2.88	24.06	.0082	122.1
91	1050.6	1109.7	.71	28.47	.0022	456.6	141	1015.7	1124.9	2.95	23.91	.0084	119.2
92	1049.9	1110.0	.74	28.42	.0023	442.5	142	1015.0	1125.2	3.03	23.75	.0086	116.3
93	1049.2	1110.3	.76	28.37	.0023	429.2	143	1014.3	1125.5	3.11	23.59	.0088	113.5
94	1048.5	1110.6	.78	28.32	.0024	416.7	144	1013.6	1125.9	3.19	23.43	.0090	110.7
95	1047.8	1110.9	.81	28.27	.0025	404.8	145	1012.9	1126.2	3.27	23.26	.0092	108.1
96	1047.2	1111.2	.83	28.22	.0025	393.7	146	1012.2	1126.5	3.35	23.09	.0095	105.5
97	1046.5	1111.5	.86	28.17	.0026	381.7	147	1011.5	1126.8	3.44	22.92	.0097	103.0
98	1045.3	1111.8	.89	28.12	.0027	370.4	148	1010.8	1127.1	3.53	22.74	.0099	100.7
99	1045.1	1112.1	.91	28.06	.0028	358.8	149	1010.1	1127.4	3.61	22.56	.0102	98.42
100	1044.4	1112.4	.94	28.00	.0029	349.6	150	1009.4	1127.7	3.71	22.37	.0104	96.16
101	1043.7	1112.7	.97	27.94	.0029	340.1	151	1008.7	1128.0	3.80	22.18	.0106	93.99
102	1043.0	1113.0	1.00	27.88	.0030	331.1	152	1008.0	1128.3	3.90	21.99	.0109	91.84
103	1042.3	1113.4	1.03	27.82	.0031	321.6	153	1007.3	1128.6	3.99	21.79	.0111	89.78
104	1041.6	1113.7	1.06	27.76	.0032	312.5	154	1006.6	1128.9	4.09	21.59	.0114	87.72
105	1040.9	1114.0	1.09	27.69	.0033	303.3	155	1005.9	1129.2	4.19	21.39	.0117	85.70
106	1040.2	1114.3	1.13	27.63	.0034	294.1	156	1005.2	1129.5	4.29	21.18	.0119	83 76
107	1039.5	1114.6	1.15	27.56	.0035	285.7	157	1004.5	1129.8	4.40	20.96	.0122	81.84
108	1038.8	1114.9	1.19	27.49	.0036	277.8	158	1003.8	1130.1	4.51	20.74	.0125	80.00
109	1038.1	1115.2	1.23	27.42	.0037	270.3	159	1003.1	1130.4	4.62	20.52	.0128	78.19

FACTORS OF EVAPORATION.

Boiler Pressure.

Feed Temp.	0	5	10	15	20	25	30	35	40	45	50	60	70	80	90	100	120	140	160	180	200
212	1.000	1.005	1.009	1.012	1.015	1.018	1.020	1.022	1.024	1.025	1.027	1.030	1.033	1.035	1.038	1.040	1.044	1.047	1.050	1.053	1.055
215	.....	1.002	1.006	1.009	1.012	1.014	1.017	1.019	1.021	1.022	1.024	1.027	1.030	1.032	1.035	1.037	1.040	1.043	1.047	1.049	1.052
220	.....	.996	1.001	1.004	1.007	1.009	1.012	1.014	1.015	1.017	1.019	1.022	1.025	1.027	1.029	1.031	1.035	1.038	1.042	1.044	1.047
225	.....	.991	.995	.998	1.002	1.004	1.006	1.009	1.010	1.012	1.013	1.016	1.019	1.022	1.024	1.026	1.029	1.033	1.036	1.039	1.042
230	.....	.....	.990	.993	.996	.998	1.001	1.003	1.005	1.006	1.008	1.011	1.014	1.017	1.019	1.021	1.024	1.028	1.031	1.034	1.037
235	.....	.....	.985	.988	.991	.993	.996	.998	1.000	1.001	1.003	1.006	1.009	1.011	1.013	1.015	1.019	1.023	1.026	1.029	1.031
240	.....	.....	.979	.983	.986	.988	.991	.993	.994	.996	.997	1.000	1.003	1.006	1.008	1.010	1.013	1.017	1.020	1.023	1.026
245	.....	.....	.....	.977	.981	.983	.986	.988	.989	.991	.992	.995	.998	1.001	1.003	1.005	1.008	1.012	1.015	1.018	1.021
250	.....	.....	.....	.972	.975	.977	.980	.982	.984	.986	.987	.990	.993	.996	.998	1.000	1.003	1.007	1.010	1.013	1.016
255	.....	.....	.....	.....	.970	.972	.975	.977	.979	.980	.982	.985	.988	.991	.993	.995	.998	1.002	1.005	1.007	1.010
260	.....	.....	.....	.....	.....	.967	.970	.971	.973	.975	.977	.980	.983	.986	.988	.989	.993	.997	1.000	1.002	1.005
265	.....	.....	.....	.....	.....	.962	.965	.966	.968	.970	.971	.974	.977	.980	.982	.984	.988	.992	.995	.997	1.000
270	.....	.....	.....	.....	.....	.....	.959	.961	.963	.965	.966	.969	.972	.975	.977	.978	.982	.986	.989	.992	.995
275	.....	.....	.....	.....	.....	.....	.....	.956	.958	.960	.961	.964	.967	.970	.971	.973	.977	.981	.984	.987	.990
280	.....	.....	.....	.....	.....	.....	.....	.950	.952	.954	.955	.958	.961	.964	.966	.968	.971	.975	.978	.981	.984
285	.....	.....	.....	.....	.....	.....	.....	.....	.947	.949	.950	.953	.956	.959	.961	.963	.966	.970	.973	.976	.979
290	.....	.....	.....	.....	.....	.....	.....	.....	.....	.944	.945	.948	.951	.954	.956	.957	.961	.965	.968	.971	.973
295	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.939	.942	.945	.948	.950	.952	.956	.959	.962	.965	.968
300	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.937	.940	.943	.945	.947	.950	.954	.957	.959	.962
305	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.932	.935	.938	.940	.942	.945	.949	.952	.954	.957
310	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.929	.932	.934	.936	.939	.943	.946	.949	.952
315	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.924	.927	.929	.931	.934	.938	.941	.944	.947
320	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.921	.924	.925	.929	.932	.935	.938	.941
325	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.918	.920	.924	.927	.930	.933	.936
330	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.913	.915	.919	.922	.925	.928	.931

Example: 5000 lbs. of water at 240° F. are evaporated per hour to steam at 160 lbs. pressure. What is the equivalent evaporation from and at 212° F.? Under 160 lbs. find opposite 240° the factor, 1.020; $5000 \times 1.020 = 5100$ lbs. of water from and at 212° F.

Flow of Steam through Pipes.—The approximate weight of any fluid which will flow in one minute through any given pipe with a given head or pressure may be found by the following formula:

$$W = 87 \sqrt{\frac{D(p_1 - p_2)d^5}{L\left(1 + \frac{3.6}{d}\right)}}$$

in which W = weight in pounds avoirdupois, d = diameter in inches, D = density or weight per cubic foot, p_1 = the initial pressure, p_2 = pressure at end of pipe, and L = the length in feet.

The following table gives, approximately, the weight of steam per minute which will flow from various initial pressures, with one pound loss of pressure through straight smooth pipes, each having a length of 240 times its own diameter.

For sizes of pipe below 6-inch, the flow is calculated from the *actual* areas of "standard" pipe of such nominal diameters.

For horse-power, multiply the figures in the table by 2. For any other loss of pressure, multiply by the square root of the given loss. For any other length of pipe, *divide 240 by the given length expressed in diameters, and multiply the figures in the table by the square root of this quotient,* which will give the flow for 1 lb. loss of pressure. Conversely, dividing the given length by 240 will give the loss of pressure for the flow given in the table.

The loss of head due to getting up the velocity, to the friction of the steam entering the pipe, and passing elbows and valves, will reduce the flow given in the tables. The resistance at the opening, and that at a globe valve, are each about the same as that for a length of pipe equal to 114 diameters divided by a number represented by 1 + (33.6 ÷ diameter). For the sizes of pipes given in the table, these corresponding lengths are:

¾	1	1½	2	2½	3	4	5	6	8	10	12	15	18
20	25	34	41	47	52	60	66	71	79	84	88	92	95

The resistance at an elbow is equal to ⅔ that of a globe valve. These equivalents—for opening, for elbows, and for valves—must be added in each instance to the actual length of pipe. Thus a 4 in. pipe, 120 diameter (40 feet) long, with a globe valve and three

TABLE OF FLOW OF STEAM THROUGH PIPES.

Initial Pressure by Gauge. Pounds per Square Inch.	Diameter of Pipe, in Inches. Length of Each = 240 Diameters.													
	¾	1	1½	2	2½	3	4	5	6	8	10	12	15	18
	Weight of Steam per Minute, in Pounds, with One Pound Loss of Pressure.													
1	1.12	2.05	5.65	10.15	15.26	25.12	46.27	76.1	111.6	209.1	336.3	495.3	792	1160
10	1.38	2.54	6.98	12.54	18.85	31.03	57.15	93.9	137.9	258.2	415.3	611.8	979	1433
20	1.62	2.97	8.18	14.70	22.09	36.36	66.97	110.1	161.6	302.6	486.7	716.9	1147	1679
30	1.82	2.34	9.21	16.54	24.86	40.92	75.37	123.9	181.8	340.6	547.8	806.9	1291	1889
40	2.01	3.68	10.12	18.18	27.34	44.99	82.87	136.3	199.9	374.5	602.3	887.2	1419	2078
50	2.17	3.98	10.95	19.67	29.57	48.67	89.64	147.4	206.3	404.9	651.5	959.7	1535	2248
60	2.32	4.25	11.71	21.04	31.63	52.06	95.89	157.7	231.3	433.3	696.9	1026.5	1642	2404
70	2.46	4.51	12.42	22.32	33.55	55.22	101.71	167.3	245.4	459.6	739.3	1088.9	1742	2550
80	2.59	4.75	13.09	23.52	35.36	58.19	107.18	176.3	258.6	484.3	778.9	1147.4	1836	2687
90	2.71	4.96	13.66	24.55	36.91	60.74	111.88	183.9	269.9	505.5	811.5	1197.8	1916	2805
100	2.84	5.20	14.32	25.73	38.71	63.66	117.25	192.8	282.9	529.8	852.2	1255.3	2008	2940
120	3.06	5.61	15.44	27.75	41.71	68.64	126.43	207.9	305.1	571.3	918.9	1353.6	2166	3170
150	3.37	6.16	16.97	30.49	45.83	75.42	138.91	228.4	335.2	627.7	1009.6	1487.2	2379	3483

elbows, would be equivalent to $120+60+60+(3\times40)=360$ diameters long; and $360\div240=1\frac{1}{2}$. It would therefore have $1\frac{1}{2}$ lbs. loss of pressure at the flow given in the table, or deliver $(1\div\sqrt{1\frac{1}{2}}=.816)$ 81.6 per cent. of the steam with the same (1 lb.) loss of pressure.

Flow of Steam from a Given Orifice.—Steam of any pressure flowing through an opening into any other pressure, less than three-fifths of the initial, has practically a constant velocity, 888 feet per second, or a little over ten miles per minute; hence the amount discharged in pounds is proportionate to the weight or density of the steam. To ascertain the pounds, avoirdupois, discharged per minute, *multiply the area of opening in inches, by 370 times the weight per cubic foot of the steam.*

Or the quantity discharged per minute may be approximately found by Rankine's formula:

$$W=6\,ap\div7$$

in which $W=$ weight in pounds, $a=$ area in square inches, and $p=$ absolute pressure. The theoretical flow requires to be multiplied by $k=0.93$, for a short pipe, or 0.63 for a thin opening, as in a plate, or a safety valve.

Where the steam flows into a pressure more than $\frac{2}{3}$ the pressure in the boiler:

$$W=1.9\,ak\sqrt{(p-\delta)\delta}$$

in which $\delta=$ difference in pressure between the two sides, in pounds per square inch, and a, p and k as above.

To reduce to horse-power, multiply by 2.

Where a given horse-power is required to flow through a given opening, to determine the necessary difference in pressure:

$$\delta=\frac{p}{2}-\sqrt{\frac{p^2}{4}-\frac{\text{H.P.}^2}{14a^2k}}$$

Equation of Pipes.—It is frequently desirable to know what number of one-sized pipes will be equal in capacity to another given pipe for delivery of steam, air or water. At the same velocity of flow two pipes deliver as the squares of their internal diameters, but the same head will not produce the same velocity in pipes of different sizes or lengths, the difference being usually stated to vary

as the square root of the fifth power of the diameter. The friction of a fluid within itself is very slight, and therefore the main resistance to flow is the friction upon the sides of the conduit. This extends to a limited distance, and is, of course, greater in proportion to the contents of a small pipe than of a large. It may be approximated in a given pipe by a constant multiplied by the diameter, or the ratio of flow found by dividing some power of the diameter by the diameter increased by a constant. Careful comparison of a large number of experiments, by different investigators, has developed the following as a close approximation to the relative flow in pipes of different sizes under similar conditions:

$$W = \sqrt{\frac{d^6}{d + 3.6}} \quad \text{or,} \quad \frac{d^3}{\sqrt{d + 3.6}}$$

W being the weight of fluid delivered in a given time, and d being the internal diameter in inches.

The diameters of "standard" steam and gas pipe, however, vary from the nominal diameters, and in applying this rule it is necessary to take the true measurements, which are given in the following table:

TABLE OF STANDARD SIZES, STEAM AND GAS PIPES.

Size, Inches.	Diameter.		Size, Inches.	Diameter.		Size, Inches.	Diameter.	
	Internal.	External.		Internal.	External.		Internal.	External.
⅛	.27	.40	2½	2.47	2.87	9	8.94	9.62
¼	.36	.54	3	3.07	3.5	10	10.02	10.75
⅜	.49	.67	3½	3.55	4	11	11.22	12.0
½	.62	.84	4	4.03	4.5	12	12.18	13
¾	.82	1.05	4½	4.51	5	13	13.14	14
1	1.05	1.31	5	5.04	5.56	14	14.09	15
1¼	1.38	1.66	6	6.06	6.62	15	15.05	16
1½	1.61	1.90	7	7.02	7.62	16	16.00	17
2	2.07	2.37	8	7.98	8.62	17	16.96	18

The table below gives the number of pipes of one size required to equal in delivery other larger pipes of the same length and under same conditions. The upper portion above the diagonal line of blanks pertains to "standard" steam and gas pipes, while the lower portion is for pipes of the *actual* internal diameters given. The figures given in the table opposite the intersection of any two sizes is the number of the smaller sized pipes required to equal one of the larger. Thus, it requires 29 standard 2 inch pipes to equal one standard 7 inch pipe.

TABLE OF EQUATION OF PIPES.—STANDARD STEAM AND GAS PIPES.

Diam.	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Diam.
½		2.27	4.88	15.8	31.7	52.9	96.9	205	377	620	918	1,292	1,767	2,488	3,014	3,786	4,904	5,927	7,321	8,535	9,717	½
¾	2.60		2.05	6.97	14.0	23.3	42.5	90.4	166	273	405	569	779	1,096	1,328	1,668	2,161	2,615	3,226	3,761	4,282	¾
1	7.55	2.90		3.45	6.82	11.4	20.9	44.1	81.1	133	198	278	380	536	649	815	1,070	1,263	1,576	1,837	2,092	1
1½	24.2	9 30	3.20		2.00	3.34	6.13	13.0	23.8	39.2	58.1	81.7	112	157	190	239	310	375	463	539	614	1½
2	54 8	21.0	7.25	2.26		1.67	3.06	6.47	11.9	19.6	29.0	40.8	55.8	78.5	95.1	119	155	187	231	269	307	2
2½	102	39 4	13.6	4.23	1.87		1.83	3.87	7,12	11.7	17.4	24.4	33.4	47.0	56.9	71.5	92.6	112	138	161	184	2½
3	170	65.4	22.6	7 03	3.11	1.66		2.12	3.89	6.39	9.48	13.3	20.9	23.7	31.2	39.1	50.6	61.1	75.5	88.0	100	3
4	376	144	49.8	15.5	6.87	3.67	2.21		1.84	3.02	4.48	6.30	8.61	12.1	14.7	18.5	23.9	28.9	35.7	41 6	47.4	4
5	686	263	90 9	28.3	12.5	6.70	4 03	1.83		1.65	2.44	3.43	4.69	6.60	8.00	10.0	13.0	15.7	19.4	22.6	25.8	5
6	1,116	429	148	46.0	20.4	10.9	6.56	2.97	1.63		1.48	2.09	2.85	4.02	4.86	6.11	7.91	9.56	11.8	13.8	15.6	6
7	1,707	656	226	70.5	31.2	16.6	10.0	4.54	2.49	1.51		1.41	1.93	2.71	3.28	4.12	5.34	6.45	7.97	9.31	10.6	7
8	2,435	936	322	101	44.5	23.8	14.3	6.48	3.54	2.18	1.43		1.35	1.93	2.33	2.92	3.79	4.57	5.67	6.60	7.52	8
9	3,335	1,281	440	137	60.8	32.5	19.5	8.85	4.85	2.98	1.95	1.37		1.41	1.71	2.14	2.77	3.35	4.14	4 83	5.50	9
10	4,393	1,688	582	181	80.4	42.9	25.8	11.7	6.40	3.93	2.57	1.80	1.32		1.21	1.52	1.97	2.38	2.94	3.43	3.91	10
11	5,642	2,168	747	233	103	55.1	33.1	15.0	8.22	5.05	3.31	2.32	1.70	1.28		1.26	1.63	1.88	2.43	2.83	3.22	11
12	7,087	2,723	938	293	129	69.2	41.6	18.8	10.3	6.34	4.15	2.91	2.13	1.61	1.26		1.30	1.57	1.93	2.26	2.58	12
13	8,657	3,326	1,146	358	158	84.5	50.7	23.0	12.6	7.75	5.07	3.56	2.60	1.98	1.53	1.22		1 21	1.49	1.74	1.98	13
14	10,600	4,070	1,403	438	193	103	62.2	28.2	15.4	9.48	6.21	4.35	3.18	2.41	1.88	1.50	1 22		1.24	1.44	1.64	14
15	12,824	4,927	1,698	530	234	125	75.3	34.1	18.7	11.5	7.52	5.27	3.85	2.92	2.27	1.81	1.48	1.21		1.17	1.35	15
16	14,978	5,758	1,984	619	274	146	88.0	39.9	21.8	13.4	8.78	6.15	4.51	3.41	2.66	2.12	1.73	1.42	1.18		1.14	16
17	17,537	6,738	2,322	724	320	171	103	46.6	25.6	15.7	10.3	7.20	5.27	3.99	3.11	2.47	2.03	1.66	1.37	1.17		
18	20,327	7,810	2,691	840	371	198	119	54.1	29 6	18.2	11.9	8.35	6.11	4.63	3.60	2.87	2.35	1.92	1.59	1.36	1.16	
20	26,676	10,249	3,532	1,102	487	260	157	70 9	38.9	23.9	15.6	10 9	8.02	6.07	4.73	3.76	3.08	2.52	2.08	1.78	1.52	
24	42,624	16,376	5,644	1,761	778	416	250	113	62 1	38.2	25.0	17.5	12.8	9.70	7.55	6.01	4.92	4.02	3 32.	2.84	2.43	
30	75,453	28,990	9,990	3,117	1,378	736	443	201	110	67.6	44.2	31.0	22.7	17.2	13 4	10.7	8.72	7.14	5.88	5.03	4.30	
36	120,100	46,143	15,902	4,961	2,193	1,172	705	319	175	108	70.4	49.3	36.1	27.3	21.3	16.9	13.9	11.3	9.37	8.01	6.85	
42	177,724	68,282	23,531	7,341	3,245	1,734	1,044	473	259	159	104	73.0	53.4	40.5	31.5	25.1	20.5	16.8	13.9	11.9	10.1	
48	249,351	95,818	33,020	10,301	4,554	2,434	1,465	663	363	223	146	102	75.0	56.8	44.2	35 2	28.8	23.5	19.4	16.6	14.2	
Diam.	½	¾	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	

ACTUAL INTERNAL DIAMETERS.

FLOW OF AIR THROUGH AN ORIFICE IN CUBIC FEET OF FREE AIR PER MINUTE.

FLOWING FROM A ROUND HOLE IN RECEIVER INTO THE ATMOSPHERE. RECEIVER GAUGE PRESSURE.

Diameter of Orifice, Inches.	2 Pounds.	5 Pounds.	10 Pounds.	15 Pounds.	20 Pounds.	25 Pounds.	30 Pounds.	35 Pounds.	40 Pounds.	45 Pounds.	50 Pounds.	60 Pounds.	70 Pounds.	80 Pounds.	90 Pounds.	100 Pounds.	125 Pounds.
1/64	.038	.0597	.0842	.103	.119	.133	.156	.173	.19	.208	.225	.26	.295	.33	.364	.40	.486
1/32	.153	.242	.342	.418	.485	.54	.632	.71	.77	.843	.914	1.05	1.19	1.33	1.47	1.61	1.97
1/16	.647	.965	1.36	1.67	1.93	2.16	2.52	2.80	3.07	3.36	3.64	4.2	4.76	5.32	5.87	6.45	7.85
1/8	2.435	3.86	5.45	6.65	7.7	8.6	10	11.2	12.27	13.4	14.50	10.8	19.0	21.2	23.50	25.8	31.4
1/4	9.74	15.40	21.8	26.70	30.8	34.5	40	44.7	49.09	53.8	58.2	67	76	85	94	103	125
3/8	21.95	34.60	49.0	60.00	69	77	90	100	110.45	121	130	151	171	191	211	231	282
1/2	39.00	61.60	87.0	107	123	138	161	179	196.35	215	232	268	04	340	376	412	502
5/8	61.00	96.50	136	167	193	216	252	280	306.80	336	364	420	476	532	587	645	785
3/4	87.60	133	196	240	277	310	362	400	441.79	482	522	604	685	765	843	925	
7/8	119.50	189	267	326	378	422	493	550	601.32	658	710	622	930	1004			
1	156.00	247	350	427	494	550	645	715	785.40	860	930						
1 1/4	242.00	384	543	665	770	860	1000										
1 1/2	350.00	550	780	960													
2	625.00	985															

NUMBER OF THERMAL UNITS (B.T.U.) REQUIRED TO HEAT A GIVEN QUANTITY OF DRY AIR A CERTAIN NUMBER OF DEGREES FAHRENHEIT, COMMENCING AT 32° F.

Cubic Feet.	Heated.								
	1°	2°	3°	4°	5°	6°	7°	8°	9°
100	1.92	3.84	5.76	7.68	9.60	11.52	13.44	15.36	17.28
200	3.84	7.68	11.52	15.36	19.20	23.04	26.88	30.72	34.56
300	5.76	11.52	17.28	23.04	28.80	34.56	40.32	46.08	51.84
400	7.68	15.36	23.04	30.72	38.40	46.08	53.76	61.44	69.12
500	9.60	19.20	28.80	38.40	48.00	57.60	67.20	76.80	86.40
600	11.52	23.00	34.56	46.08	57.60	69.12	80.64	92.16	103.68
700	13.44	26.88	40.32	53.76	67.20	80.64	94.08	107.52	120.96
800	15.36	30.72	46.08	61.44	76.80	92.16	107.52	122 88	138.24
900	17.28	34.56	51.84	69.12	86.40	103 68	120.96	138.24	155.52

WEIGHT OF AIR.

Cubic Feet of Air.	Weight of Dry Air at Different Temperatures, the Barometer Standing at 29.92 Inches of Mercury.															
	32°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°	95°	100°	105°	110°
100	8.07	8.02	7.94	7.86	7.79	7 71	7.64	7.57	7.50	7.43	7.36	7.29	7.23	7.16	7.10	7.03	6.97
200	16.14	16.04	15.88	15.72	15.58	15.42	15.28	15.14	15	4.86	14.72	14.58	14.46	14.32	14.20	14.06	13.94
300	24.21	24.06	23.82	23.58	23.37	23.13	22.92	22.71	22.50	22.29	22.08	21.87	21.69	21.48	21.30	21.09	20.91
400	32.28	32.08	31.76	31.44	31.16	30.84	30.56	30.28	30	29.72	29.44	29.16	28.92	28.64	28.40	28.12	27.88
500	40.35	40.10	39.70	39.30	38.95	38.55	38.20	37.85	37.50	37.15	36.80	36.45	36.15	35.80	35.50	35.15	34.85
600	48.42	48.12	47.64	47.16	46.74	46.26	45.84	45.42	45	44.58	44.16	43.74	43.38	42.96	42.60	42.18	41.82
700	56.49	56.14	55.58	55.02	54.53	53.97	53.48	52.99	52.50	52.01	51.52	51.03	50.61	50.12	49.70	49.21	48.79
800	64.56	64.16	63.52	62.88	62.32	61.68	61.12	60.56	60	59.44	58.88	58.32	57.84	57.28	56.80	56.24	55.76
900	72.63	72.18	71.46	70.74	70.11	69.39	68.76	68.13	67.50	66.87	66.24	65.61	65.07	64.44	63.90	63.27	62.73

HEAT REQUIRED TO WARM AIR.

Pounds of Air.	Number of Thermal Units (B.T.U.) Required to Heat a Given Quantity of Dry Air a Certain Number of Degrees Fahrenheit.							
	1° 33	2° 34	3° 35	4° 36	5° 37	6° 38	7° 39	8° 40	9° 41
100	23.79	47.58	71.37	95.16	118.95	142.74	166.53	190.32	214.11
200	47.58	95.16	142.74	190.32	237.90	285.48	333.06	380.64	428.22
300	71.37	142.74	214.11	285.48	356.85	428.22	499.59	570.96	642.33
400	95.16	190.32	285.48	380.64	475.80	570.96	666.12	761.28	856.44
500	118.95	237.90	356.85	475.80	594.75	713.70	832.65	951.60	1070.55
600	142.74	285.48	428.22	570.96	713.70	856.44	999.18	1141.92	1284.66
700	166.53	333.06	499.59	666.12	832.65	999.18	1165.71	1332.24	1498.77
800	190.32	380.64	570.96	761.28	951.60	1141.92	1332.24	1522.56	1712.88
900	214.11	428.22	642.33	856.44	1070.54	1284.66	1498.77	1712.88	1926.99

EFFECT OF TEMPERATURE UPON THE MOVEMENT OF AIR.

Temperature in Degrees Fahrenheit.	Relative Velocity Due to the Same Pressure.	Relative Pressure Necessary to Produce the Same Velocity.	Relative Weight of Air Moved at the Same Velocity.	Relative Velocity Necessary to Move the Same Weight of Air.	Relative Pressure Necessary to Produce the Velocity to Move the Same Weight of Air.	Relative Power Necessary to Move the Same Volume of Air at the Same Velocity.	Relative Power Necessary to Move Same Weight of Air at the Velocity in Column 5 and the Pressure in Column 6.
1	2	3	4	5	6	7	8
30	0.98	1.04	1.04	0.96	0.96	1.04	0.92
40	0.99	1.02	1.02	0.98	0.98	1.02	0 96
50	1.00	1.00	1.00	1,00	1.00	1.00	1.00
60	1.01	0.98	0.98	1.02	1.02	0.98	1.04
70	1.02	0.96	0.96	1.04	1.04	0.96	1.08
80	1.03	0.94	0.94	1.06	1.06	0.94	1.12
90	1.04	0.93	0.93	1.08	1.08	0.93	1.17
100	1.05	0.91	0.91	1.10	1.10	0.91	1.21
125	1.07	0.87	0.87	1.15	1.15	0.87	1.32
150	1.09	0.84	0.84	1.20	1.20	0.84	1.43
175	1.11	0.81	0.81	1.24	1.24	0.81	1.55
200	1.14	0.78	0.78	1.29	1.29	0.78	1.67
225	1.16	0.75	0.75	1.34	1.34	0.75	1.80
250	1.18	0.72	0.72	1.39	1.39	0.72	1.93
275	1.20	0.69	0.69	1.44	1.44	0.69	2.07
300	1.22	0.67	0.67	1.49	1.49	0.67	2.22
325	1.24	0.65	0.65	1.54	1.54	0.65	2.36
350	1.26	0.63	0.63	1.59	1.59	0.63	2.51
375	1.28	0.61	0.61	1.63	1.63	0.61	2.66
400	1.30	0.59	0.59	1.68	1.68	0.59	2.82
425	1.32	0.58	0.58	1.73	1.73	0.58	2.99
450	1.34	0.56	0.56	1.78	1.78	0.56	3.17
475	1.35	0.55	0.55	1.83	1.83	0.55	3.35
500	1.37	0.53	0.53	1.88	1.88	0.53	3.53
525	1.39	0.52	0.52	1.93	1.93	0.52	3.72
550	1.41	0.51	0.51	1.98	1.98	0.51	3.92
575	1.43	0.49	0.49	2.03	2.03	0.49	4.12
600	1.44	0.48	0 48	2.08	2.08	0.48	4.33
625	1.46	0.47	0.47	2.13	2.13	0.47	4.54
650	1.48	0.46	0.46	2.18	2.18	0.46	4.75
675	1.49	0.45	0 45	2.22	2.22	0 45	4.93
700	1.51	0.44	0.44	2.27	2.27	0.44	5.15
725	1.52	0.43	0.43	2.32	2.32	0.43	5.38
750	1.54	0.42	0.42	2.37	2.37	0.42	5.62
775	1.56	0.41	0.41	2.42	2.42	0.41	5.86
800	1.57	0.40	0.40	2.47	2.47	0.40	6.10

EQUALIZATION TABLE.

This table is based upon the laws of friction of gases in pipes, and is designed to equalize the combined capacities of a number of small pipes to that of the main conduit.

EXAMPLE.—It is desired to connect thirty 8-inch pipes to one main, the problem being to determine the diameter of the latter. The usual rule would be to multiply the area of an 8-inch pipe by 30, resulting in a 44-inch main. By the table it will be seen that thirty 8-inch pipes require a main of only 31 inches in diameter to carry the same volume of air. The figures at the top of the column are the diameters of the branches, those at the left hand side the diameter of the mains.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1																														
2	5.7																													
3	16	2.7																												
4	32	5.7	2.3																											
5	56	9.7	3.6	1.8																										
6	88	16	5.7	2.8	1.6																									
7	129	23	8.3	4.1	2.3	1.5																								
8	180	32	12	5.7	3.2	2.1	1.4																							
9	244	42	16	7.6	4.3	2.8	1.9	1.3																						
10	317	56	20	9.9	5.7	3.6	2.4	1.7	1.3																					
11	402	71	26	12	7.0	4.5	3.1	2.2	1.7	1.3																				
12	501	88	32	16	9.0	5.7	3.8	2.8	2.0	1.6	1.2																			
13	613	107	39	19	11	6.9	4.7	3.4	2.5	1.9	1.5	1.2																		
14	737	129	47	23	13	8.3	5.7	4.1	3.0	2.3	1.8	1.5	1.2																	
15	876	152	56	27	16	9.9	6.7	4.8	3.6	2.8	2.2	1.8	1.4	1.2																
16	1026	180	65	32	18	11	7.9	5.7	4.2	3.2	2.6	2.1	1.7	1.4	1.2															
17	1197	208	76	37	21	13	9.2	6.6	4.9	3.8	2.9	2.4	2.0	1.6	1.4	1.2														
18	1375	239	88	43	24	16	10	7.7	5.7	4.3	3.4	2.8	2.3	1.9	1.6	1.3	1.2													
19	1580	275	100	49	28	18	12	8.8	6.5	5.0	3.9	3.2	2.6	2.2	1.8	1.5	1.3	1.2												
20	1775	312	114	56	32	20	14	9.9	7.4	5.7	4.5	3.6	2.9	2.5	2.1	1.7	1.5	1.3	1.1											
21	1985	345	130	61	35	22	15	10	8.4	6.3	5.2	4.1	3.2	2.6	2.3	2.0	1.6	1.4	1.2	1.1										
22	2250	398	145	71	41	26	18	13	9.3	7.2	5.7	4.5	3.7	3.1	2.6	2.2	1.9	1.7	1.4	1.3	1.1									
23	2525	460	160	77	47	29	20	14	10	7.8	6.2	5.0	4.1	3.4	2.8	2.4	2.1	1.8	1.6	1.4	1.2	1.1								
24	2800	493	180	88	50	32	22	16	12	8.9	7.6	5.7	4.6	3.8	3.2	2.9	2.4	2.1	1.8	1.6	1.3	1.2	1.1							
25	3060	543	202	97	55	35	24	17	13	10	8.0	6.4	5.2	4.2	3.5	3.1	2.6	2.2	2.0	1.7	1.5	1.3	1.2	1.1						
26	3425	590	219	108	62	39	27	19	14	11	8.6	6.9	5.7	4.7	4.0	3.4	2.9	2.5	2.2	1.9	1.7	1.5	1.3	1.2	1.1					
27	3738	677	243	121	68	43	29	21	15	12	9.6	7.5	6.1	5.1	4.3	3.6	3.1	2.7	2.4	2.1	1.9	1.6	1.5	1.3	1.2	1.1				
28	4100	725	265	129	74	48	32	23	17	13	10	8.3	6.8	5.7	4.8	4.1	3.5	3.0	2.6	2.3	2.1	1.8	1.6	1.5	1.3	1.2	1.1			
29	4440	800	289	141	79	52	35	25	19	14	11	9.1	7.5	6.2	5.2	4.4	3.8	3.3	2.9	2.5	2.2	2.0	1.8	1.6	1.4	1.3	1.2	1.1		
30	4898	864	315	151	88	56	38	28	20	16	12	9.9	8.0	6.7	5.7	4.7	4.1	3.6	3.0	2.6	2.4	2.2	1.9	1.7	1.5	1.4	1.3	1.2	1.1	
31	5312	920	344	168	96	59	40	30	22	17	13	10	8.9	7.4	6.1	5.1	4.5	3.9	3.4	3.0	2.7	2.4	2.1	1.9	1.7	1.5	1.4	1.3	1.2	1.1
32	5631	1070	374	184	103	63	42	32	23	18	14	11	9.3	8.0	6.5	5.7	4.8	4.2	3.7	3.2	2.8	2.5	2.3	2.0	1.8	1.6	1.5	1.4	1.3	1.1
33	6154	1140	401	196	109	70	45	35	25	19	15	12	10	8.5	7.1	6.0	5.2	4.4	3.9	3.5	3.0	2.7	2.4	2.2	2.0	1.8	1.6	1.5	1.3	1.2
34	6675	1208	433	212	119	76	51	37	27	21	16	13	11	9.1	7.6	6.4	5.5	4.8	4.2	3.7	3.3	2.9	2.6	2.4	2.1	1.9	1.7	1.6	1.5	1.3
35	7075	1280	470	229	127	82	56	40	30	23	18	14	12	10	8.4	7.1	6.1	5.3	4.6	4.0	3.5	3.1	2.8	2.5	2.3	2.1	1.9	1.7	1.5	1.4
36	7735	1355	497	242	138	88	60	43	32	25	19	16	13	11	8.9	7.6	6.5	5.7	5.0	4.3	3.7	3.4	3.0	2.7	2.4	2.2	2.0	1.9	1.7	1.6
37	8265	1435	537	260	146	94	64	45	33	26	20	16	13	11	9.3	7.9	6.9	6.0	5.3	4.6	4.0	3.6	3.2	2.9	2.6	2.3	2.1	1.9	1.8	1.6*
38	8715	1625	575	279	157	100	68	49	37	29	22	18	14	12	10	8.6	7.4	6.3	5.5	4.8	4.3	3.8	3.4	3.1	2.8	2.5	2.3	2.1	1.9	1.8

PRESSURE IN OUNCES PER SQUARE INCH.

INCHES OF WATER COLUMN AND THE CORRESPONDING SPOUTING VELOCITIES.

Pressures per Square Inch in Ounces.	Height of Water Column in Inches.	Air Velocities, Feet per Minute.	Pressures per Square Inch in Ounces.	Height of Water Column in Inches.	Air Velocities, Feet per Minute.
2	3.468	7338.24	12	20.808	18350.34
3	5.202	9006.42	13	22.542	19138.26
4	6.936	10421.58	14	24.276	19900.68
5	8.670	11676.00	15	26.01	20640.48
6	10.404	12817.08	16	27.75	21360.00
7	12.138	13872.72	17	29.478	22060.80
8	13.872	14861.16	18	31.212	22745.40
9	15.606	15795.06	19	32.946	23415.00
10	17.340	16683.51	20	34.680	24070.80
11	19.074	17533.50			

1 lb. Pressure $\begin{cases} = 2.0376 \text{ inches of mercury,} \\ = 2.31 \text{ feet of water.} \\ = 27.672 \text{ inches of water.} \end{cases}$

AIR PRESSURES IN INCHES OF WATER. OUNCES PER SQUARE INCH AND THEIR CORRESPONDING VELOCITIES.

Pressure per Square Inch in Inches of Water.	Corresponding Pressure in Ounces per Square Inch.	Velocity Due to the Pressure in Feet per Minute.
1/32	.01817	696.78
1/16	.03634	987.66
1/8	07268	1393.75
3/16	10902	1707.00
1/4	14536	1971.30
5/16	18170	2204.16
3/8	.21804	2414.70
1/2	.29072	2788.74
5/8	.36340	3118.38
3/4	.43608	3416.64
7/8	.50870	3690.62
1	.58140	3946.17
1 1/4	.7267	4362.62
1 1/2	.8724	4836.06
1 3/4	1.0174	5224.98
2	1.1628	5587.58

PRESSURE AND HORSE-POWER CONSUMED BY THE FRICTION OF AIR PASSING THROUGH PIPES 100 FEET LONG.

Velocity of Air in Feet per Minute.	Diameter of Pipe																			
	1-inch.		2-inch.		3-inch.		4-inch.		5-inch.		6-inch.		7-inch.		8-inch.		9-inch.		10-inch.	
	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.
100	0.011	0.0000	0.004	0.0000	0.004	0.0000	0.003	0.0000	0.002	0.0000	0.002	0.0000	0.002	0.0000	0.001	0.0000	0.001	0.0000	0.001	0.0000
200	0.044	0.0000	0.022	0.0000	0.015	0.0000	0.011	0.0001	0.009	0.0001	0.007	0.0001	0.006	0.0001	0.006	0.0001	0.005	0.0001	0.004	0.0001
300	0 100	0.0000	0.050	0.0001	0.033	0.0001	0.025	0.0002	0.020	0.0002	0.017	0.0003	0.014	0.0003	0.012	0.0004	0.011	0.0004	0.010	0.0004
400	0.178	0.0001	0.088	0.0002	0.059	0.0003	0.044	0.0004	0.036	0.0005	0.030	0.0006	0.025	0.0007	0.022	0.0008	0.020	0.0009	0.018	0.0011
500	0.278	0.0002	0.139	0.0004	0.092	0.0006	0.069	0.0008	0.056	0.0010	0.046	0.0012	0.040	0.0014	0.035	0.0017	0.031	0.0019	0.028	0.0021
600	0.400	0.0004	0.200	0.0007	0.133	0.0011	0.100	0.0014	0.080	0.0018	0.067	0.0021	0.057	0.0025	0.050	0.0029	0.044	0.0032	0.040	0.0036
700	0.544	0.0006	0.272	0.0011	0.181	0.0017	0.138	0.0023	0.109	0.0028	0.091	0.0034	0.078	0.0040	0.068	0.0045	0.060	0.0051	0.054	0.0057
800	0.711	0.0008	0.356	0.0017	0.237	0.0025	0.178	0.0034	0.142	0.0042	0.119	0.0051	0.102	0.0059	0.089	0.0067	0.079	0.0076	0.071	0.0085
900	0.900	0.0012	0.450	0.0024	0.300	0.0036	0.225	0.0048	0.180	0.0060	0.150	0.0072	0.129	0.0084	0.112	0.0096	0.100	0.0108	0.090	0.0120
1,000	1.111	0.0017	0.556	0.0033	0.370	0.0049	0.278	0.0066	0.222	0.0083	0.185	0.0099	0.159	0.0116	0.139	0.0132	0.123	0.0148	0.111	0.0165
1,100	1.344	0.0022	0.672	0.0044	0.448	0.0066	0.338	0.0088	0.269	0.0110	0.224	0.0132	0.192	0.0154	0.168	0.0176	0.149	0.0198	0.134	0.0220
1,200	1.600	0.0029	0.800	0.0057	0.533	0.0086	0.400	0.0114	0.320	0.0143	0.267	0.0171	0.229	0.0200	0.200	0.0230	0.178	0.0256	0.160	0.0286
1,300	1.878	0.0036	0.939	0.0073	0.626	0.0109	0.469	0.0145	0.376	0.0182	0.313	0.0218	0.268	0.0254	0.235	0.0290	0.209	0.0327	0.188	0.0363
1,400	2.178	0.0045	1.089	0.0090	0.726	0.0136	0.544	0.0181	0.436	0.0227	0.363	0.0272	0.311	0.0317	0.282	0.0363	0.242	0.0408	0.218	0.0453
1,500	2.500	0.0056	1.250	0.0112	0.833	0.0167	0.625	0.0223	0.500	0.0279	0.417	0.0335	0.357	0.0390	0.312	0.0446	0.278	0.0502	0.250	0.0558
1,600	2.844	0.0068	1.422	0.0135	0.948	0.0203	0.711	0.0271	0.569	0.0338	0.474	0.0406	0.406	0.0473	0.356	0.0541	0.316	0.0609	0.284	0.0677
1,700	3.211	0.0081	1.605	0.0162	1.070	0.0244	0.803	0.0325	0.642	0.0406	0.535	0.0487	0.459	0.0508	0.401	0.0649	0.357	0.0731	0.321	0.0812
1,800	3.600	0.0096	1.800	0.0192	1.200	0.0289	0.900	0.0385	0.720	0.0482	0.600	0.0578	0.514	0.0674	0.450	0.0771	0.400	0.0867	0.360	0.0964
1,900	4.011	0.0113	2.006	0.0227	1.337	0.0340	1.003	0.0453	0.802	0.0567	0.669	0.0680	0.573	0.0793	0.501	0.0977	0.446	0.1020	0.401	0.1133
2,000	4.444	0.0132	2.222	0.0264	1.481	0.0397	1.111	0.0529	0.889	0.0661	0.741	0.0793	0.635	0.0925	0.556	0.1058	0.493	0.1190	0.444	0.1322
2,200	5.378	0.0176	2.689	0.0352	1.793	0.0528	1.344	0.0704	1.076	0.0880	0.896	0.1161	0.683	0.1232	0.672	0.1408	0.597	0.1583	0.538	0.1760
2,400	6.400	0.0228	3.200	0.0457	2.133	0.0685	1.600	0.0914	1.280	0.1142	1.067	0.1371	0.914	0.1600	0.800	0.1728	0.711	0.2056	0.640	0.2284
2,600	7.511	0.0290	3.756	0.0581	2.504	0.0871	1.877	0.1162	1.502	0.1452	1.252	0.1743	1.073	0.2033	0.939	0.2324	0.835	0.2614	0.751	0.2904
2,800	8.711	0.0363	4.356	0.0726	2.904	0.1088	2.178	0.1451	1.742	0.1814	1.452	0.2177	1.244	0.2539	1.089	0.2902	0.968	0.3265	0.871	0.3628
3,000	10.000	0.0446	5.000	0.0892	3.333	0.1339	2.500	0.1785	2.000	0.2231	1.667	0.2677	1.429	0.3123	1.250	0.3569	1.111	0.4016	1.000	0.4462
3,200	11.378	0.0541	5.689	0.1083	3.792	0.1625	2.844	0.2166	2.276	0.2708	1.896	0.3249	1.625	0.3790	1.422	0.4332	1.263	0.4873	1.138	0.5415
3,400	12.844	0.0649	6.422	0.1299	4.281	0.1949	3.211	0.2598	2.569	0.3247	2.141	0.3897	1.835	0.4546	1.606	0.5237	1.427	0.5845	1.284	0.6495
3,600	14.400	0.0770	7.200	0.1542	4.800	0.2313	3.600	0.3084	2.880	0.3855	2.400	0.4626	2.057	0.5397	1.800	0.6168	1.600	0.7039	1.440	0.7710
3,800	16.044	0 0906	8.022	0.1814	5.349	0.2720	4.011	0.3627	3.209	0.4534	2.674	0.5441	2.292	0.6347	2.006	0.7254	1.783	0.8171	1.604	0.9068
4,000	17.778	0.1058	8.889	0.2115	5.926	0.3173	4.444	0.4230	3.556	0.5288	2.963	0.6346	2.540	0.7403	2.222	0.8461	1.975	0.9518	1.778	1.0576
4,200			9.800	0.2448	6.553	0.3673	4.900	0.4897	3.920	0.6121	3.267	0.7346	2.800	0.8570	2.450	0.9794	2.178	1.1019	1.960	1.2243
4,400			10.705	0.2815	7.175	0.4223	5.353	0.5631	4.282	0.7038	3.569	0.8446	3.059	0.9854	2.676	1.1261	2.379	1.2669	2.141	1.4077
4,800			12.800	0.3655	8.533	0.5484	6.400	0.7310	5.120	0.9138	4.267	1.0964	3.657	1.2793	3.200	1.4620	2.844	1.6448	2.560	1.8275
5,200			15.022	0.4747	10.015	0.6971	8.511	0.9294	6.008	1.1618	5.007	1.3941	4.292	1.6265	3.756	1.8588	3.339	2.0912	3.004	2.3236
5,600			17.422	0.5804	11.615	0.8707	8.711	1.1608	6.969	1.4510	5.807	1.7412	4.978	2.0314	4.356	2.3216	3.872	2.6118	3.484	2.9021
6,000			20.000	0.7139	13.333	1.0710	10.000	1.4278	8.000	1.7847	6.667	2.1416	5.714	2.4986	5.000	2.8555	4.444	3.2125	4.000	3.5694

PRESSURE AND HORSE-POWER CONSUMED BY THE FRICTION OF AIR PASSING THROUGH PIPES 100 FEET LONG.—*Continued.*

Velocity of Air in Feet per Minute.	Diameter of Pipe.																			
	11-inch.		12-inch.		13-inch.		14-inch.		16-inch.		18-inch.		20-inch.		22-inch.		24-inch.		26-inch.	
	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.
100	0.001	0.0000	0.001	0.0000	0.001	0.0000	0.001	0.0000	0.001	0.0000	0.001	0.0000	0.001	0.0000	0.001	0.0000	0.000	0.0000	0.000	0.0000
200	0.004	0.0001	0.004	0.0002	0.003	0.0002	0.003	0.0002	0.003	0.0002	0.002	0.0002	0.002	0.0003	0.002	0.0003	0.004	0.0003	0.002	0.0003
300	0.009	0.0005	0.008	0.0005	0.008	0.0006	0.007	0.0006	0.006	0.0007	0.006	0.0008	0.005	0.0009	0.005	0.0010	0.002	0.0011	0.004	0.0012
400	0.016	0.0012	0.015	0.0013	0.014	0.0014	0.013	0.0015	0.011	0.0017	0.010	0.0019	0.009	0.0021	0.008	0.0023	0.007	0.0025	0.007	0.0027
500	0.025	0.0023	0.023	0.0025	0.021	0.0027	0.020	0.0029	0.017	0.0033	0.016	0.0037	0.014	0.0041	0.013	0.0045	0.012	0.0050	0.011	0.0054
600	0.036	0.0039	0.033	0.0043	0.031	0.0046	0.029	0.0050	0.025	0.0057	0.022	0.0064	0.020	0.0071	0.018	0.0079	0.017	0.0086	0.015	0.0093
700	0.049	0.0062	0.045	0.0068	0.041	0.0074	0.039	0.0079	0.034	0.0091	0.030	0.0102	0.027	0.0113	0.025	0.0125	0.023	0.0136	0.021	0.0147
800	0.064	0.0093	0.059	0.0102	0.055	0.0109	0.051	0.0118	0.044	0.0135	0.040	0.0152	0.036	0.0169	0.032	0.0186	0.029	0.0203	0.027	0.0220
900	0.081	0.0132	0.075	0.0145	0.069	0.0157	0.064	0.0169	0.056	0.0193	0.050	0.0217	0.045	0.0241	0.041	0.0265	0.037	0.0289	0.035	0.0313
1,000	0.101	0.0182	0.092	0.0198	0.085	0.0215	0.079	0.0231	0.069	0.0264	0.062	0.0297	0.056	0.0330	0.051	0.0364	0.046	0.0397	0.043	0.0430
1,100	0.122	0.0242	0.112	0.0264	0.103	0.0286	0.096	0.0308	0.084	0.0352	0.075	0.0396	0.067	0.0440	0.061	0.0484	0.056	0.0528	0.052	0.0572
1,200	0.145	0.0314	0.133	0.0343	0.123	0.0371	0.114	0.0400	0.100	0.0457	0.089	0.0512	0.080	0.0571	0.073	0.0628	0.067	0.0685	0.062	0.0742
1,300	0.170	0.0399	0.156	0.0437	0.144	0.0472	0.134	0.0508	0.117	0.0581	0.104	0.0654	0.094	0.0726	0.085	0.0799	0.078	0.0873	0.072	0.0944
1,400	0.198	0.0499	0.181	0.0544	0.167	0.0589	0.156	0.0635	0.136	0.0726	0.121	0.0816	0.109	0.0907	0.099	0.0998	0.091	0.1088	0.084	0.1179
1,500	0.227	0.0613	0.208	0.0669	0.192	0.0725	0.179	0.0781	0.156	0.0892	0.139	0.1004	0.125	0.1115	0.114	0.1227	0.104	0.1339	0.096	0.1450
1,600	0.259	0.0735	0.237	0.0812	0.219	0.0880	0.203	0.0948	0.178	0.1083	0.158	0.1218	0.142	0.1354	0.129	0.1469	0.119	0.1624	0.109	0.1760
1,700	0.292	0.0893	0.268	0.0974	0.247	0.1055	0.229	0.1137	0.207	0.1299	0.178	0.1461	0.161	0.1624	0.146	0.1786	0.134	0.1948	0.124	0.2110
1,800	0.327	0.1060	0.300	0.1156	0.278	0.1253	0.257	0.1351	0.225	0.1542	0.200	0.1735	0.180	0.1927	0.164	0.2120	0.150	0.2313	0.139	0.2506
1,900	0.365	0.1247	0.334	0.1360	0.308	0.1472	0.287	0.1587	0.251	0.1814	0.223	0.2040	0.201	0.2267	0.182	0.2494	0.167	0.2720	0.154	0.2945
2,000	0.404	0.1454	0.370	0.1586	0.341	0.1719	0.317	0.1851	0.278	0.2115	0.247	0.2380	0.222	0.2644	0.202	0.2908	0.185	0.3173	0.171	0.3437
2,200	0.489	0.1936	0.448	0.2111	0.413	0.2287	0.384	0.2463	0.336	0.2815	0.299	0.3167	0.269	0.3519	0.244	0.3871	0.224	0.4223	0.207	0.4575
2,400	0.582	0.2513	0.533	0.2741	0.492	0.2970	0.457	0.3198	0.400	0.3455	0.356	0.4112	0.320	0.4569	0.291	0.5026	0.267	0.5483	0.246	0.5939
2,600	0.683	0.3195	0.626	0.3485	0.578	0.3776	0.537	0.4066	0.468	0.4647	0.417	0.5228	0.376	0.5809	0.341	0.6390	0.313	0.6971	0.289	0.7552
2,800	0.792	0.3990	0.726	0.4353	0.670	0.4716	0.622	0.5079	0.544	0.5804	0.484	0.6530	0.436	0.7255	0.396	0.7981	0.363	0.8706	0.335	0.9432
3,000	0.909	0.4908	0.833	0.5354	0.769	0.5800	0.714	0.6245	0.625	0.7140	0.556	0.8031	0.500	0.8923	0.455	0.9816	0.417	1.0708	0.385	1.1601
3,200	1.034	0.5956	0.948	0.6498	0.875	0.7039	0.813	0.7581	0.711	0.8664	0.632	0.9747	0.569	1.0830	0.517	1.1913	0.474	1.2996	0.438	1.4079
3,400	1.168	0.7144	1.070	0.7794	0.988	0.8441	0.917	0.9093	0.827	1.0475	0.714	1.1690	0.642	1.2990	0.584	1.4289	0.535	1.5588	0.494	1.6882
3,600	1.309	0.8481	1.200	0.9252	1.114	1.0023	1.029	1.0800	0.900	1.2335	0.800	1.4078	0.720	1.5420	0.655	1.6962	0.600	1.8504	0.557	2.0046
3,800	1.459	0.9974	1.337	1.0871	1.234	1.1880	1.146	1.2695	1.003	1.4508	0.891	1.6342	0.802	1.8135	0.729	1.9949	0.669	2.1742	0.617	2.3650
4,000	1.616	1.1734	1.481	1.2691	1.367	1.3749	1.270	1.4807	1.111	1.6922	0.988	1.9037	0.889	2.1152	0.808	2.3467	0.741	2.5382	0.684	2.7493
4,200	1.782	1.3667	1.633	1.4692	1.508	1.5916	1.400	1.7140	1.225	1.9589	1.089	2.2037	0.980	2.4486	0.891	2.7335	0.817	2.9383	0.754	3.1839
4,400	1.946	1.5484	1.784	1.6892	1.655	1.8300	1.537	1.9707	1.344	2.2522	1.189	2.5338	1.071	2.8153	0.973	3.0969	0.892	3.3784	0.827	2.7455
4,800	2.327	2.0103	2.133	2.1930	1.969	2.3758	1.829	2.5585	1.600	2.9241	1.422	3.2896	1.280	3.6551	1.164	4.0206	1.067	4.3861	0.985	8.6972
5,200	2.731	2.5559	2.504	2.7882	2.311	3.0206	2.146	3.2530	1.871	3.7177	1.670	4.1824	1.502	4.6471	1.366	5.1118	1.252	5.5565	1.156	1.6464
5,600	3.168	3.1923	2.904	3.4825	2.680	3.7727	2.489	4.0629	2.178	4.6433	1.936	5.2237	1.742	5.8041	1.584	6.3845	1.452	6.9649	1.340	5.9150
6,000	3.636	3.9263	3.333	4.2833	3.077	4.6402	2.857	4.9959	2.500	5.7110	2.222	6.4249	2.000	7.1388	1.818	7.8527	1.667	8.5666	1.538	0.4283

PRESSURE AND HORSE-POWER CONSUMED BY THE FRICTION OF AIR PASSING THROUGH PIPES 100 FEET LONG.—*Continued.*

Velocity of Air in Feet per Minute.	Diameter of Pipe.																	
	28-inch.		30-inch.		32-inch.		36-inch.		40-inch.		44-inch.		48-inch.		52-inch.		56-inch.		60-inch.	
	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.	Loss of Pressure in oz. per sq. in.	H.P. Lost in Friction.
100	0.000	0.0000	0.000	0.0001	0.000	0.0001	0.000	0.0001	0.000	0.0001	0.000	0.0001	0.000	0.0001	0.000	0.0001	0.000	0.0001	0.000	0.0001
200	0.002	0.0004	0.001	0.0004	0.001	0.0004	0.001	0.0005	0.001	0.0005	0.001	0.0006	0.001	0.0006	0.001	0.0007	0.001	0.0007	0.001	0.0008
300	0.004	0.0012	0.003	0.0014	0.003	0.0014	0.003	0.0016	0.002	0.0018	0.002	0.0020	0.002	0.0021	0.002	0.0023	0.002	0.0025	0.002	0.0027
400	0.006	0.0030	0.006	0.0032	0.006	0.0034	0.005	0.0038	0.004	0.0042	0.004	0.0047	0.004	0.0051	0.003	0.0055	0.003	0.0059	0.003	0.0063
500	0.010	0.0058	0.009	0.0062	0.009	0.0066	0.008	0.0074	0.007	0.0083	0.006	0.0091	0.006	0.0099	0.005	0.0107	0.005	0.0116	0.005	0.0124
600	0.014	0.0100	0.013	0.0107	0.012	0.0114	0.011	0.0128	0.010	0.0143	0.009	0.0157	0.008	0.0171	0.008	0.0186	0.007	0.0200	0.007	0.0214
700	0.019	0.0159	0.018	0.0170	0.017	0.0181	0.015	0.0204	0.014	0.0227	0.012	0.0249	0.011	0.0272	0.010	0.0295	0.010	0.0317	0.009	0.0340
800	0.025	0.0237	0.024	0.0254	0.022	0.0271	0.020	0.0305	0.018	0.0339	0.016	0.0372	0.015	0.0406	0.014	0.0440	0.013	0.0474	0.012	0.0508
900	0.032	0.0337	0.030	0.0361	0.028	0.0385	0.025	0.0434	0.022	0.0482	0.020	0.0530	0.019	0.0578	0.017	0.0626	0.016	0.0675	0.015	0.0723
1,000	0.040	0.0463	0.037	0.0496	0.035	0.0569	0.031	0.0595	0.028	0.0661	0.025	0.0727	0.023	0.0793	0.021	0.0859	0.020	0.0925	0.019	0.0991
1,100	0.048	0.0616	0.045	0.0660	0.042	0.0704	0.035	0.0792	0.034	0.0880	0.030	0.0968	0.028	0.1055	0.026	0.1144	0.024	0.1232	0.022	0.1320
1,200	0.057	0.0800	0.053	0.0857	0.050	0.0914	0.044	0.1024	0.040	0.1142	0.036	0.1256	0.033	0.1371	0.031	0.1485	0.029	0.1599	0.027	0.1713
1,300	0.067	0.1017	0.063	0.1089	0.058	0.1162	0.052	0.1307	0.047	0.1452	0.043	0.1597	0.039	0 1746	0.036	0.1888	0.034	0.2033	0.031	0.2178
1,400	0.078	0.1270	0.073	0.1360	0.068	0.1451	0.060	0.1632	0.054	0.1814	0.049	0.1995	0.045	0.2177	0.042	0.2360	0 039	0.2539	0.036	0.2721
1,500	0.089	0.1562	0.083	0.1673	0.078	0.1785	0.069	0.2008	0.062	0.2231	0.057	0.2454	0.052	0.2677	0.048	0.2900	0.045	0.3123	0.042	0.3346
1,600	0.102	0.1895	0.095	0.2031	0.089	0.2166	0.079	0.2437	0.071	0.2707	0.069	0.2938	0.059	0.3249	0.055	0.3520	0.051	0.3790	0.047	0.4061
1,700	0.115	0.2273	0.107	0.2436	0.103	0.2598	0.089	0.2923	0.080	0.3247	0.073	0.3572	0.067	0.3897	0.062	0.4220	0.057	0.4546	0.054	0.4871
1,800	0.129	0.2702	0.120	0.2891	0.112	0.3084	0.100	0.3469	0.090	0.3855	0.082	0.4240	0.075	0.4626	0.069	0.5011	0.064	0.5406	0.060	0.5782
1,900	0.143	0.3174	0.134	0.3401	0.125	0.3627	0.111	0.4080	0.103	0.4534	0.091	0.4987	0.084	0.5440	0.077	0.5890	0.072	0.6347	0.067	0.6800
2,000	0.159	0.3702	0.148	0.3966	0.139	0.4230	0.123	0.4759	0.111	0.5288	0.101	0.5817	0.093	0.6346	0.085	0.6874	0.079	0.7403	0.074	0.7932
2,200	0.192	0.4927	0.179	0.5279	0.168	0.5631	0.149	0.6334	0.134	0.7038	0.122	0.7742	0.112	0.8446	0.103	0.9150	0.096	0.9854	0.090	1.1607
2,400	0.239	0.6396	0.213	0.6855	0.200	0.6910	0.178	0.8224	0.160	0.9138	0.145	1.0051	0.133	1.0965	0.123	1.1879	0.119	1.2793	0.107	1.3706
2,600	0.268	0.8132	0.250	0.8714	0.234	0.9294	0.209	1.0456	0.188	1.1618	0.171	1.2779	0.156	1.3941	0.144	1.5103	0.134	1.6265	0.125	1.7427
2,800	0.311	1.0157	0.290	1.0884	0.272	1.1608	0.242	1.3059	0.218	1.4510	0.198	1.5961	0.181	1.7412	0.168	1.8864	0.156	2.0314	0.145	2.1765
3,000	0.357	1.2490	0.333	1.3388	0.312	1.4280	0.278	1.6062	0.250	1.7847	0.227	1.9632	0.208	2.1416	0.192	2.3201	0.179	2.4979	0.167	2.6771
3,200	0.406	1.5162	0.379	1.6246	0.356	1.7328	0.316	1.9494	0.284	2 1660	0.259	2.3826	0.237	2.5992	0.219	2.8157	0.203	3.0324	0.190	3.2489
3,400	0.459	1.8186	0.428	1.9487	0.413	2.0950	0.357	2.3382	0.321	2.5980	0.292	2.8578	0.268	3.1176	0.247	3.3764	0.229	3.6372	0.214	3.8970
3,600	0.514	2.1620	0.480	2.3132	0.450	2.4671	0.400	2.8156	0.360	3.0840	0.327	3.3924	0.300	3.7007	0.279	4.0091	0.257	4.3239	0.240	4.6259
3,800	0.573	2.5389	0.535	2.7206	0.501	2.9016	0.446	3.2683	0.401	3.6270	0.365	3.9897	0.334	4.3484	0.309	4.7519	0.287	5.0779	0.267	5.4406
4,000	0.635	2.9613	0.593	3.1731	0.556	3.3843	0.494	3.8074	0.444	4.2304	0.404	4.6934	0.370	5.0765	0.342	5.4995	0.317	5.9226	0.296	6.3456
4,200	0.700	3.4281	0.653	3.6729	0.612	3.9178	0.544	4.4075	0.490	4.8972	0.445	5.4669	0.408	5.8767	0.377	6.3664	0 350	6.8561	0.327	7.3458
4,400	0.768	3.9415	0.717	4.2234	0.672	4.5045	0.595	5.0676	0.535	5.6307	0.487	6.1937	0.446	6.7568	0.414	7.3199	0.384	7.8829	0.357	8.4460
4,800	0.914	5.1171	0.853	5.4836	0.800	5.8481	0.711	6.5791	0.640	7.3101	0.582	8.0411	0.533	8.7722	0.492	9.5032	0.457	10.2342	0.427	10.9642
5,200	1.073	6.5059	1.011	6.9713	0.935	7.4354	0.835	8.3648	0.751	9.2942	0.683	10.2236	0.626	11.1530	0.578	12.0824	0.537	13.0119	0.501	13.9413
5,600	1.244	8.1258	1.161	8.7070	1.089	9.2866	0.968	10.4474	0.871	11.6082	0.792	12.7690	0.726	13.9300	0.670	15.0907	0.622	16.2515	0.581	17.4123
6,000	1.429	9.9918	1.333	10.7100	1.250	11.4221	1.111	12.8498	1.000	14.2776	0.909	15.7054	0.833	17.1331	0.769	18.5609	0.714	19.9835	0.667	21.4164

NUMBER OF SQUARE INCHES OF FLUE AREA REQUIRED PER 1,000 CUBIC FEET OF CONTENTS FOR GIVEN VELOCITY AND AIR CHANGE.

No. Minutes to Change Air.	Velocity of Air in Flue in Feet Per Minute.												
	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500
4	120	90	72	60	51.6	45	40	36	32.2	30	27.6	25.6	21.4
5	06	72.2	57.6	48	41.1	36.1	32	28.8	26.2	24	22.2	20.5	19.2
6	80	60	48	40	34.3	30	26.6	24	21.8	20	18.5	17.1	16
7	68.6	51.4	41.1	34.3	29.4	25.7	22.9	20.6	18.7	17.2	15.7	14.7	13.7
8	60	45	36	30	25.8	22.5	20	18	16.1	15	13.8	12.8	12
9	53.3	40	32	26.6	22.9	20	17.8	16	14.5	13.3	12.3	11.4	10.7
10	48	36	28.8	24	20.6	18	16	14.4	13.1	12	11.1	10.3	9.6
11	43.6	32.2	25.2	21.8	18.7	16.1	14.5	13.1	11.9	10.9	10.1	9.5	8.7
12	40	30	24	20	17.2	15	13.3	12	10.9	10	9.2	8 6	8
13	36.9	27.7	22.2	18.5	15.7	13.8	12.3	11.1	10.1	9.2	8.5	7.9	7.4
14	34.3	25.7	20.6	17.2	14.7	12.8	11.4	10.3	9.5	8.6	7.9	7.4	6.9
15	32	24	19.2	16	13.7	12	10.7	9.6	8.7	8	7.4	6.9	6.4
16	30	22.5	18	15	12.9	11.2	10	9	8.2	7.5	6.9	6.4	6
17	28.2	21.2	16.9	14.1	12.1	10.6	9.4	8.5	7.7	7	6.5	6.1	5.6
18	26.6	20	16	13.3	11.5	10	8.9	8	7.3	6.6	6.2	5.7	5.3
19	25.3	18.9	15.2	12.6	10.8	9.5	8.4	7.6	6.9	6.3	5.8	5.4	5.1
20	24	18	14.4	12	10.3	9	8	7.2	6.5	6	5.5	5.1	4.8

To facilitate calculation of flue areas for different requirements in heating, ventilation and the general movement of air, the table above and that upon the two succeeding pages have been prepared. The former is to be employed when in a ventilating system the area of the flue is to be based upon the time required to change the air within the room and upon the permissible velocity in the flue. The latter table indicates the flue area necessary for the passage of a predetermined volume of air at a stated velocity. Values for volumes below 100 or above 1,000 cubic feet may be readily determined from the latter table by reading for the multiple of the given volume, and then pointing off the requisite number of places. Thus, if a volume of 8,750 cubic feet of air is required to pass through a flue at a velocity of 900 feet per minute, the cross sectional area of that flue must be 1,400 square inches.

FLUE AREA REQUIRED FOR THE PASSAGE OF A GIVEN VOLUME OF AIR AT A GIVEN VELOCITY.

Volume in Cubic Feet per Minute.	Velocity in Feet per Minute.													
	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600
100	48	36	29	24	21	18	16	14	13	12	11	10	9.6	9
125	60	45	36	30	26	23	20	18	16	15	14	13	12	11.3
150	72	54	43	36	31	27	24	22	20	18	16	15	14.4	13.5
175	84	63	50	42	36	32	28	25	23	21	19	18	16.8	15.8
200	96	72	58	48	41	36	32	29	26	24	22	21	19.2	18
225	108	81	65	54	46	41	36	32	29	27	25	23	21.6	20.3
250	120	90	72	60	51	45	40	36	33	30	28	26	24	22.5
275	132	99	79	66	57	50	44	40	36	33	30	28	26.4	24.8
300	144	108	86	72	62	54	48	43	39	36	33	31	28.8	27
325	156	117	94	78	67	59	52	47	43	39	36	33	31.2	29.3
350	168	126	101	84	72	63	56	50	46	42	39	36	33.6	31.5
375	180	135	108	90	77	68	60	54	49	45	42	39	36	33.8
400	192	144	115	96	82	72	64	58	52	48	44	41	38.4	36
425	204	153	122	102	87	77	68	61	56	51	47	44	40.8	38.3
450	216	162	130	108	93	81	72	65	59	54	50	46	43.2	40.5
475	228	171	137	114	98	86	76	68	62	57	53	49	45.6	42.8
500	240	180	144	120	103	90	80	72	65	60	55	51	48	45
525	252	189	151	126	108	95	84	76	69	63	58	54	50.4	47.3
550	264	198	158	132	113	99	88	79	72	66	61	57	52.8	49.5
575	276	207	166	138	118	104	92	83	75	69	64	59	55.2	51.8
600	288	216	173	144	123	108	96	86	79	72	66	62	57.6	54
625	300	225	180	150	129	113	100	90	82	75	69	64	60	56.3
650	312	234	187	156	134	117	104	94	85	78	72	67	62.4	58.5
675	324	243	194	162	139	122	108	97	88	81	75	69	64.8	60.8
700	336	252	202	168	144	126	112	101	92	84	78	72	67.2	63
725	348	261	209	174	149	131	116	104	95	87	80	75	69.6	65.3
750	360	270	216	180	154	135	120	108	98	90	83	77	72	67.5
775	372	279	223	186	159	140	124	112	101	93	86	80	74.4	69.8
800	384	288	230	192	165	144	128	115	105	96	89	82	76.8	72
825	396	297	238	198	170	149	132	119	108	99	91	85	79.2	74.3
850	408	306	245	204	175	153	136	122	111	102	94	87	81.6	76.5
875	420	315	252	210	180	158	140	126	115	105	97	90	84	78.8
900	432	324	259	216	185	162	144	130	118	108	100	93	86.4	81
925	444	333	266	222	190	167	148	133	121	111	103	95	88.8	83.3
950	456	342	274	228	195	171	152	137	124	114	105	98	91.2	85.5
975	468	351	281	234	201	176	156	140	128	117	108	100	93.6	87.8
1000	480	360	288	240	206	180	160	144	131	121	111	103	96	90

FLUE AREA REQUIRED FOR THE PASSAGE OF A GIVEN VOLUME OF AIR AT A GIVEN VELOCITY.

Volume in Cubic Feet per Minute.	Velocity in Feet per Minute.													
	1700	1800	1900	2000	2100	2200	2300	2400	2600	2700	2800	2900	3000	3100
100	8.5	8	7.6	7.2	6.9	6.6	6.3	6	5.5	5.3	5.1	5	4.8	4.6
125	10.6	10	9.5	9	8.6	8.2	7.8	7.5	6.9	6.7	6.4	6.2	6	5.8
150	12.7	12	11.4	10.8	10.3	9.8	9.4	9	8	8	7.7	7.5	7.2	7
175	14.8	14	13.3	12.6	12	11.5	11	10.5	9.7	9.3	9	8.7	8.4	8.1
200	16.9	16	15.2	14.4	13.7	13.1	12.5	12	11.1	10.7	10.3	9.9	9.6	9.3
225	19.1	18	17.1	16.2	15.6	14.7	14.1	13.5	12.5	12	11.6	11.2	10.8	10.4
250	21.2	20	19	18	17.1	16.4	15.7	15	13.9	13.3	12.9	12.4	12	11.6
275	23.3	22	21.8	19.8	18.9	18	17.2	16.5	15.2	14.7	14.1	13.7	13.2	12.8
300	25.4	24	22.7	21.6	20.6	19.6	18.8	18	16.6	16	15.4	14.9	14.4	13.9
325	27.5	26	24.6	23.4	22.3	21.3	20.6	19.5	18	17.3	16.7	16.1	15.6	15.1
350	29.6	28	26.5	25.2	24	22.9	21.9	21	19.4	18.7	18	17.4	16.8	16.3
375	31.8	30	28.4	27	25.7	24.5	23.5	22.5	20.8	20	19.3	18.6	18	17.4
400	33.9	32	30.3	28.8	27.4	26.2	25	24	22.2	21.3	20.6	19.8	19.2	18.6
425	36	34	32.2	30.6	29.1	27.8	26.6	25.5	23.5	22.7	21.9	21.1	20.4	19.7
450	38.1	36	34.1	32.4	30.9	29.5	28.2	27	24.9	24	23.1	22.3	21.6	20.9
475	40.2	38	36	34.2	32.6	31.1	29.7	28.5	26.3	25.3	24.4	23.6	22.8	22.1
500	42.4	40	37.9	36	34.3	32.7	31.3	30	27.7	26.7	25.7	24.8	24	23.2
525	44.5	42	39.8	37.8	36	34.4	32.9	31.5	29.1	28	26.9	25	25.2	24.4
550	46.6	44	41.7	38.6	37.7	36	34.4	33	30.5	29.3	28.3	27.3	26.4	25.5
575	48.7	46	43.6	41.4	39.4	37.6	36	34.5	31.9	30.7	29.6	28.5	27.6	26.7
600	50.8	48	45.5	43.2	40.11	39.3	37.6	36	33.2	32	30.8	29.7	28.8	27.8
625	52.9	50	47.4	45	42.9	40.9	39.1	37.5	34.6	33.3	32.1	31	30	29
650	55.1	52	49.3	46.8	44.6	42.5	40.7	39	36	34.7	33.4	32.2	31.2	30.2
675	57.2	54	51.2	48.6	46.3	44.1	42.3	40.5	37.5	36	34.7	33.5	32.4	31.3
700	59.3	56	53.1	50.4	48	45.8	43.8	42	38.8	37.3	36	34.7	33.6	32.5
725	61.4	58	55	52.2	49.7	47.4	45.4	43.5	40.2	38.7	37.3	36	34.8	33.6
750	63.5	60	56.9	54	51.4	49.1	47	45	41.5	40	38.6	37.2	36	34.8
775	65.6	62	58.8	56.3	53.1	50.7	48.5	46.5	42.9	41.3	39.9	38.5	37.2	36
800	67.8	64	60.6	57.6	54.9	52.4	50.1	48	44.3	42.7	41.2	39.7	38.4	37.1
825	69.9	66	62.5	59.4	56.6	54	51.7	49.5	45.7	44	42.4	40.9	39.6	38.3
850	72	68	64.4	61.2	58.4	55.6	53.2	51	47.1	45.3	43.7	42.2	40.8	39.4
875	74	70	67.3	63	60	57.3	54.8	52.5	48.5	46.7	45	43.4	42	40.6
900	76.2	72	68.2	64.8	61.7	58.9	56.3	54	49.9	48	46.3	44.6	43.2	41.8
925	78.4	74	70.1	66.6	63.4	60.5	57.9	55.5	51.3	49.3	47.6	46	44.4	42.9
950	80.5	76	72	68.4	65.1	62.2	59.5	57	52.6	50.7	48.8	47.1	45.6	44.1
975	82.6	78	73.9	70.2	66.8	63.8	61.0	58.5	54	52	50.2	48.4	46.8	45.3
1000	84.7	80	75.8	72	68.7	66	62.6	60	55.4	53.3	51.4	49.6	48	46.4

VOLUME OF AIR NECESSARY TO MAINTAIN VARIOUS STANDARDS OF PURITY.

Cubic Feet of Space in Room per Individual.	Proportion of Carbonic Acid in 10,000 Parts of the Air Not to be Exceeded at the End of One Hour.						
	6	7	8	9	10	15	20
	Cubic Feet of Air of Composition Four Parts of Carbonic Acid if 10,000 to be Supplied the First Hour.						
100	2900	1900	1400	1100	900	445	275
200	2800	1800	1300	1000	800	345	175
300	2700	1700	1200	900	700	245	75
400	2600	1600	1100	800	600	145	.....
500	2500	1500	1000	700	500	45	.....
600	2400	1400	900	600	400	.....	.....
700	2300	1300	800	500	300	.....	.....
800	2200	1200	700	400	200	.....	.....
900	2100	1100	600	300	100	.....	.....
1000	2000	1000	500	200	.....	.....	.....
1500	1500	500	.....	.....	.....	.....	.....
2000	1000	.....	.....	.....	.....	.....	.....
2500	500	.....	.....	.....	.....	.....	.....

LOSS OF WORK DUE TO HEAT IN COMPRESSING AIR FROM ATMOSPHERIC PRESSURE TO VARIOUS GAUGE PRESSURES BY SIMPLE AND COMPOUND COMPRESSION.

AIR IN EACH CYLINDER; INITIAL TEMPERATURE 60° F.

Gauge Pressure.	One Stage.		Two Stage.		Three Stage.		Four Stage.	
	Percentage of Work Lost in Terms of							
	Isothermal Compression.	Adiabatic Compression.	Isothermal Compression.	Adiabatic Compression.	Isothermal Compression.	Adiabatic Compression.	Isothermal Compression.	Adiabatic Compression.
60	29.9	23.0	13.4	11.8	8.6	7.9	4.7	4.5
70	30.6	23.4	14.1	12.4	8.7	8.0	6.1	5.7
80	32.7	24.6	14.7	12.8	9.7	8.9	6.4	6.0
90	34.7	25.8	16.1	13.8	10.5	9.5	7.3	6.8
100	36.7	26.8	16.9	14.5	10.9	9.8	7.8	7.3
125	41.1	29.2	18.5	15.6	11.6	10.4	8.8	8.1
150	44.8	30.9	20.1	16.7	12.3	10.9	9.1	8.4
200	51.2	33.9	22.2	18.1	14.0	12.3	10.5	9.5
300	61.2	37.9	25.7	20.5	16.6	14.2	12.0	10.7
400	68.7	40.7	28.9	22.4	18.2	15.4	13.1	11.5
500	70.6	41.4	31.2	23.8	19.3	16.2	14.1	12.3
600	80.4	44.5	32.8	24.7	20.4	16.9	14.9	13.0
700	85.0	46.0	34.6	25.7	21.3	17.6	16.1	13.8
800	89.5	47.2	35.7	26.3	22.0	18.1	16.2	13.9
900	93.0	48.2	37.1	27.0	22.6	18.5	16.6	14 4
1000	96.1	49.0	37.9	27.5	23.2	18.8	16.9	14.5
1200	102.8	50.7	40.3	28 8	24.8	19.9	17.7	15.0
1400	108.6	52.0	41.5	29.3	25.9	20.5	18.6	15.7
1600	113.4	53.1	43.5	30.3	26.5	20.9	19.2	16.1
1800	117.5	54.0	44.8	31.0	27.3	21.2	19.6	16.4
2000	122 0	55.0	45.8	31.4	27.5	21.5	19.9	16.57

LOSS OF WATER HEAD IN PIPE BY FRICTION.

THE FOLLOWING TABLE SHOWS THE LOSS OF HEAD BY FRICTION IN EACH 100 FEET IN LENGTH OF DIFFERENT DIAMETERS OF PIPE, WHEN DISCHARGING THE FOLLOWING QUANTITIES OF WATER PER MINUTE:

Velocity in Feet per Second.	Inside Diameter of Pipe in Inches.																					
	6		7		8		9		10		11		12		13		14		15		16		18	
	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.
2.0	.39	23.5	.33	32.0	.30	41.9	.26	53.0	.23	65.4	.21	79	.198	94	.183	110	.169	128	.158	147	.147	167	.132	212
2.2	.46	25.9	.40	35.3	.35	46.1	.31	58.3	.28	72	.25	87	.234	103	.216	121	.200	141	.187	162	.175	184	.156	233
2.4	.54	28.2	.46	38.5	.41	50.2	.36	63.6	.32	78.5	.29	95	.273	113	.252	133	.234	154	.218	176	.205	201	.182	254
2.6	.63	30.6	.54	41.7	.47	54.4	.42	68.9	.37	85.1	.34	103	.315	122	.290	144	.270	167	.252	191	.236	218	.210	275
2.8	.72	32.9	.61	44.9	.54	58.6	.48	74.2	.43	91.6	.39	111	.360	132	.332	156	.308	179	.288	206	.270	234	.240	297
3.0	.81	35.3	.69	48.1	.61	62.8	.54	79.5	.48	98.2	.44	119	.407	141	.375	166	.349	192	.325	221	.306	251	.271	318
3.2	.91	37.7	.78	51.3	.68	67.0	.60	84.8	.54	105	.49	127	.457	151	.422	177	.392	205	.366	235	.343	268	.305	339
3.4	1.02	40.0	.87	54.5	.76	71.2	.68	90.1	.61	111	.55	134	.510	160	.471	188	.438	218	.408	250	.383	284	.339	360
3.6	1.13	42.4	.96	57.7	.84	75.4	.75	95.4	.67	118	.61	142	.566	169	.522	199	.485	231	.452	265	.425	301	.377	382
3.8	1.25	44.7	1.07	60.9	.93	79.6	.83	101	.74	124	.68	150	.624	179	.576	210	.535	243	.499	280	.468	318	.416	403
4.0	1.37	47.1	1.17	64.1	1.02	83.7	.91	106	.82	131	.74	158	.685	188	.632	221	.587	256	.548	294	.513	335	.456	424
4.2	1.49	49.5	1.28	67.3	1.12	87.9	.99	111	.89	137	.81	166	.749	198	.691	232	.641	269	.598	309	.561	352	.499	445
4.4	1.62	51.8	1.39	70.5	1.22	92.1	1.08	116	.97	144	.88	174	.815	207	.751	243	.698	282	.651	324	.611	368	.542	466
4.6	1.76	54.1	1.51	73.7	1.32	96.3	1.17	122	1.05	150	.96	182	.883	217	.815	254	.757	295	.707	339	.662	385	.588	488
4.8	1.90	56.5	1.63	76.9	1.43	100	1.27	127	1.14	157	1.04	190	.954	226	.881	265	.818	308	.763	353	.715	402	.636	509
5.0	2.05	58.9	1.76	80.2	1.54	105	1.37	132	1.23	163	1.12	198	1.028	235	.949	276	.881	321	.822	368	.770	419	.685	530
5.2	2.21	61.2	1.89	83.3	1.65	109	1.47	138	1.32	170	1.20	206	1.104	245	1.020	287	.947	333	.883	383	.828	435	.736	551
5.4	2.37	63.6	2.03	86.6	1.77	113	1.57	143	1.41	177	1.28	214	1.183	254	1.092	298	1.014	346	.947	397	.888	452	.788	572
5.6	2.53	65.9	2.17	89.8	1.89	117	1.68	148	1.51	183	1.37	222	1.26	264	1.167	309	1.083	359	1.011	412	.949	469	.843	594
5.8	2.70	68.3	2.31	93.0	2.01	121	1.80	154	1.61	190	1.46	229	1.34	273	1.245	321	1.155	372	1.078	427	1.011	486	.899	615
6.0	2.87	70.7	2.46	96.2	2.15	125	1.92	159	1.71	196	1.56	237	1.43	283	1.325	332	1.229	385	1.148	442	1.076	502	.957	636
7.0	3.81	82.4	3.26	112.0	2.85	146	2.52	185	2.28	229	2.07	277	1.91	330	1.75	387	1.630	449	1.520	515	1.430	586	1.270	742

EXAMPLE. — Have 200 feet head and 600 feet of 11-inch pipe, carrying 119 cubic feet of water per minute. To find effective head: In upper right-hand column under 11-inch pipe, find 119 cubic feet; opposite this will be found the coefficient of friction for this amount of water, which is .44. Multiply this by the number of *hundred* feet of pipe, which is 6, and you will have 2.64 feet, which is the loss of head. Therefore, the effective head is 200 — 2.64 = 197.36.

LOSS OF WATER HEAD IN PIPE BY FRICTION.

THE FOLLOWING TABLES SHOW THE LOSS OF HEAD BY FRICTION IN EACH 100 FEET IN LENGTH OF DIFFERENT DIAMETERS OF PIPE, WHEN DISCHARGING THE FOLLOWING QUANTITIES OF WATER PER MINUTE:

Velocity in Feet per Second.	Inside Diameter of Pipe in Inches.																							
	20		22		24		26		28		30		33		36		39		42		45		48	
	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.	Loss of Head in Feet.	Cubic Feet per Minute.
2.0	.119	262	.103	316	.098	377	.091	442	.084	513	.079	589	.073	712	.066	848	.061	995	.057	1155	.053	1325	.050	1508
2.2	.140	288	.127	348	.116	414	.108	486	.099	564	.093	648	.085	785	.078	933	.072	1094	.067	1270	.063	1456	.059	1658
2.4	.164	314	.149	380	.136	452	.126	531	.116	616	.109	707	.100	855	.091	1018	.084	1194	.079	1385	.073	1590	.069	1809
2.6	.189	340	.171	412	.157	490	.145	575	.134	667	.126	766	.115	927	.104	1100	.097	1294	.090	1500	.084	1721	.079	1960
2.8	.216	366	.195	443	.180	528	.165	619	.153	718	.144	824	.131	1000	.119	1188	.111	1394	.103	1617	.096	1855	.090	2110
3.0	.245	393	.222	475	.204	565	.188	663	.174	770	.163	883	.148	1070	.135	1273	.125	1442	.117	1730	.109	1987	.102	2260
3.2	.275	419	.249	507	.229	603	.211	708	.195	821	.182	942	.167	1140	.152	1367	.141	1591	.131	1845	.122	2120	.115	2410
3.4	.306	445	.278	538	.255	641	.235	752	.218	872	.204	1001	.186	1210	.169	1442	.157	1690	.146	1961	.136	2250	.128	2560
3.6	.339	471	.308	570	.283	678	.261	796	.242	923	.226	1060	.206	1282	.188	1527	.174	1790	.162	2079	.151	2382	.142	2715
3.8	.374	497	.340	601	.312	716	.288	840	.267	973	.249	1119	.226	1355	.207	1612	.191	1891	.178	2190	.166	2515	.156	2865
4.0	.410	523	.373	633	.342	754	.315	885	.293	1026	.273	1178	.248	1425	.228	1697	.210	1990	.195	2310	.182	2650	.171	3016
4.2	.449	550	.408	665	.374	791	.345	929	.320	1077	.299	1237	.270	1495	.249	1782	.229	2091	.213	2422	.198	2780	.186	3165
4.4	.488	576	.444	697	.407	829	.375	973	.348	1129	.325	1296	.295	1568	.271	1866	.250	2190	.232	2540	.216	2910	.203	3318
4.6	.529	602	.482	728	.441	867	.407	1017	.378	1180	.353	1355	.321	1640	.294	1951	.271	2290	.252	2658	.235	3045	.220	3470
4.8	.572	628	.521	760	.476	905	.440	1062	.409	1231	.381	1414	.346	1710	.318	2036	.293	2389	.270	2770	.254	3180	.238	3619
5.0	.617	654	.561	792	.513	942	.474	1106	.440	1283	.411	1472	.374	1780	.342	2121	.316	2490	.294	2885	.273	3310	.256	3770
5.2	.662	680	.602	823	.552	980	.510	1150	.473	1334	.441	1531	.403	1852	.368	2206	.342	2590	.317	3000	.296	3442	.278	3920
5.4	.710	707	.645	855	.591	1018	.546	1194	.507	1385	.473	1590	.430	1922	.394	2291	.364	2689	.338	3115	.315	3578	.295	4071
5.6	.758	733	.690	887	.632	1055	.583	1239	.542	1437	.506	1649	.453	1995	.421	2376	.393	2790	.374	3230	.340	3710	.319	4222
5.8	.809	759	.735	918	.674	1093	.622	1283	.578	1488	.540	1708	.495	2065	.450	2460	.419	2886	.389	3348	.363	3840	.340	4373
6.0	.861	785	.782	950	.717	1131	.662	1327	.615	1539	.574	1767	.520	2140	.479	2545	.441	2986	.408	3461	.382	3970	.358	4524
7.0	1.143	916	1.040	1109	.953	1319	.879	1548	.817	1796	.762	2061	.693	2495	.636	2968	.586	3484	.545	4030	.509	4638	.476	5277

The following formula, deduced by Wm. Cox, gives practically the same results as the above table and will be found useful in many instances. $F = L/1000D\ (4V^2 + 5V - 2)$. Where F = friction head, L = length of pipe in feet; D = diameter of pipe in inches; V = velocity in feet per second.

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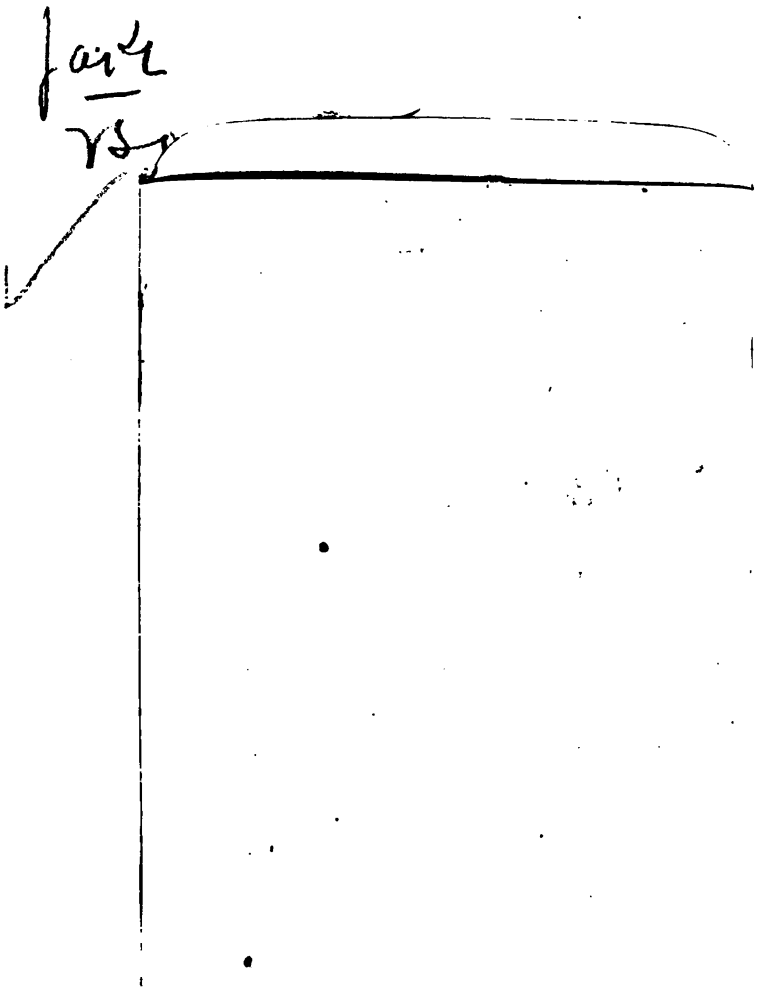

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